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ELECTRICAL REVIEW

March • 1939

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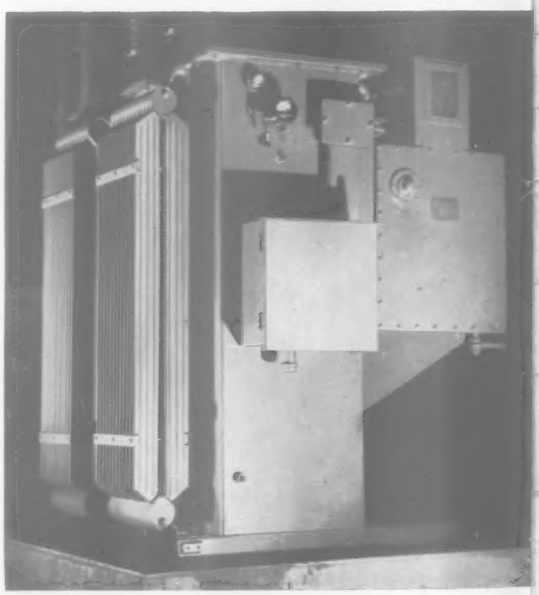

TRANSFORMER DIVISION

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ALLIS-CHALMERS ELECTRICAL REVIEW

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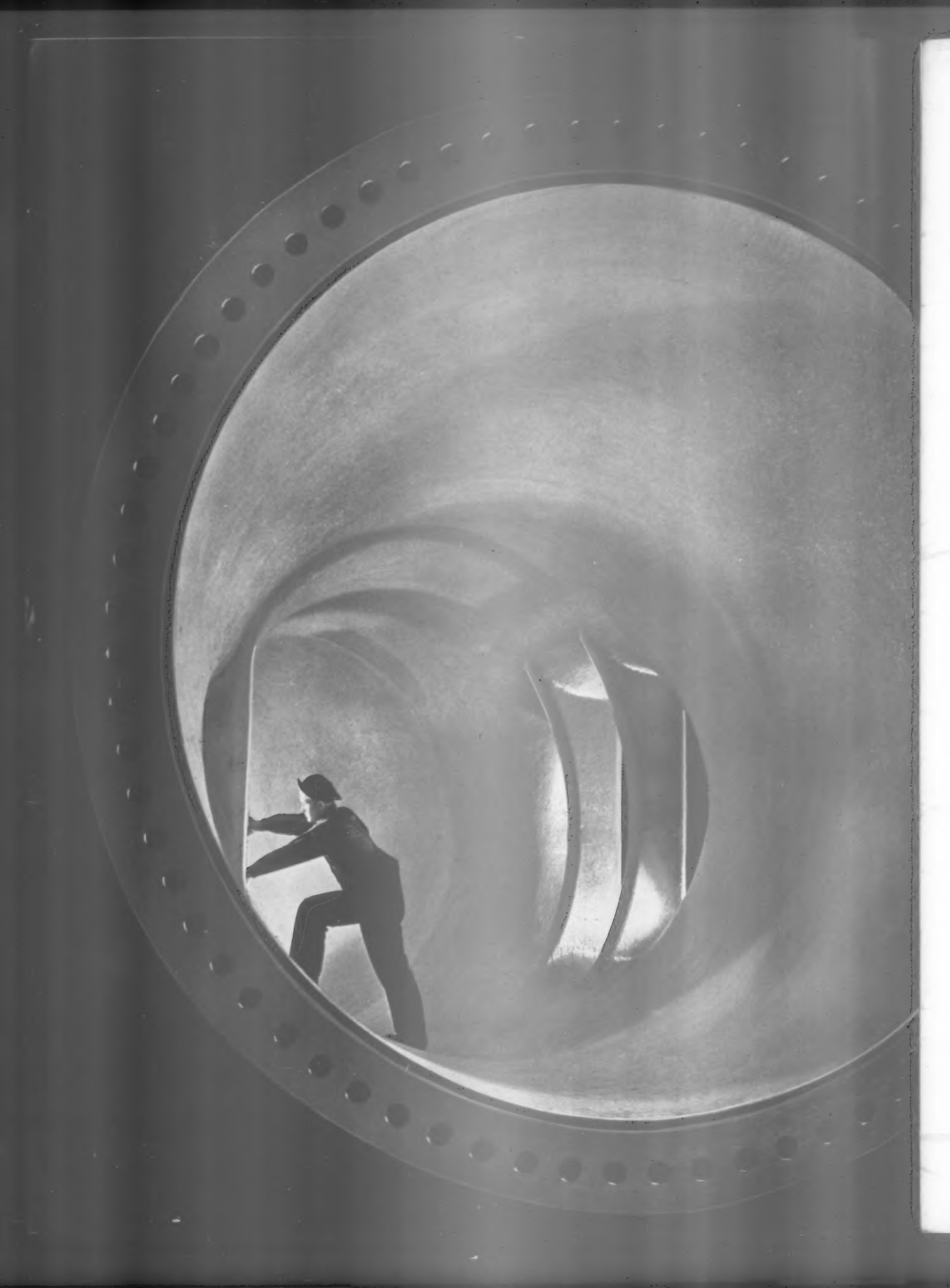

MODERN HYDRAULIC TURBINE GOVERNOR DESIGN

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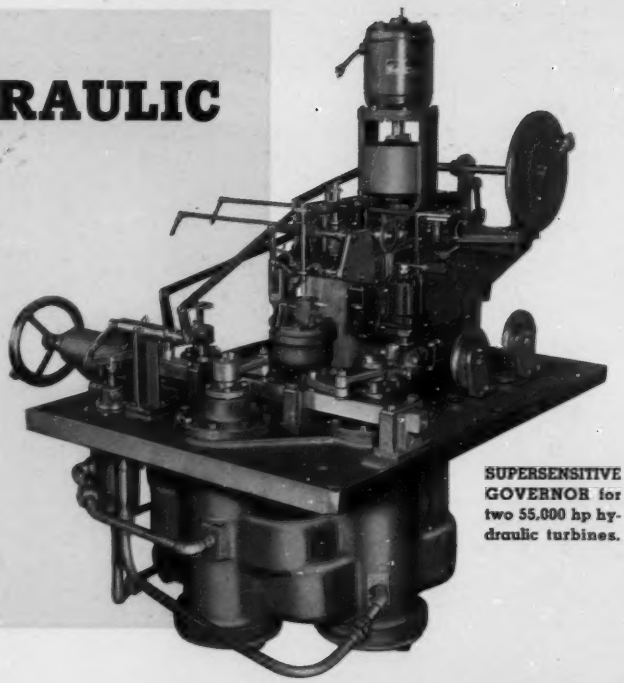
Arnold Pfau

HYDRAULIC DEPARTMENT

ALLIS-CHALMERS MANUFACTURING CO.



SUPERSENSITIVE GOVERNOR for two 55,000 hp hydraulic turbines.

In the development of an ideal hydraulic turbine governor there are three fundamental requirements to be met:

First, the governor must be sensitive enough to respond to the slightest change in speed;

Second, there must be prompt acceleration of the control mechanism of the turbine in response to the speed change;

Third, the control mechanism for adjusting the turbine output to a new load demand must be accurate.

The first requirement involves a speed responsive element commonly called the flyballs, or speed governor. This unit must respond to the slightest speed change of the turbine and produce an initial movement sufficient to cause the acceleration and movement of the control mechanism. The sensitivity of this element is of the greatest importance. Any delay in response produces an initial speed change (rise on load rejections and drop on load increases) of the revolving masses. This in turn causes delay in the movement of the control mechanism, which may produce hunting, since the movement of the control mechanism, in order to compensate for the delay, may become excessive. If the control mechanism could follow at such a rate that the resultant output would at all times be equal to the output demand or load, then the mechanism would always be in the correct position so that no after-movement would be involved.

AT LEFT: Inspecting cast steel spiral casing of one of the 115,000 hp hydraulic turbines for Boulder Dam.

To assure highest sensitivity, the friction of the moving parts producing this initial movement must be a minimum, and the initial movement itself must require a minimum of effort, as otherwise it would require a correspondingly greater speed change to accumulate energy for producing the required movement.

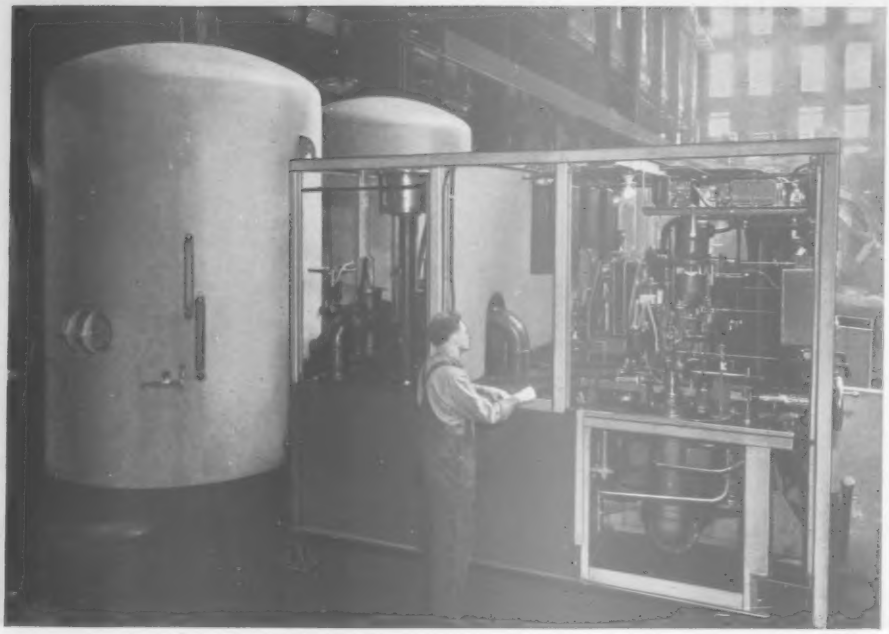
If, for example, the speed responsive element were to produce a force for moving a stem on the mechanism upward or downward of two pounds for each one percent speed change, it is evident that to produce double the force a speed change of at least two percent would be necessary. Likewise, if that same speed responsive element were called upon to produce a force of only 1/100 pounds to produce movement of the stem, the speed change necessary, neglecting initial friction, would be only 1/200 percent.

The second requirement involves a servomotor which produces the necessary foot pounds to move the control mechanism of the turbine. In order to act promptly, the fluid to the servomotor cylinder must be applied in as large a quantity as possible through a control or distributing valve actuated from the speed responsive element of the governor.

The third requirement involves the so-called restoring mechanism, which adjusts the movement of the servomotor to the position of the element responding to the speed change.

• Operation

The control valve of the governor distributes the fluid under pressure on the two sides of the operating piston of the servomotor, whereby the output of the turbine is changed. When the over-pressure force upon the piston of the servomotor equals the



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GOVERNOR-CABINET showing pressure tanks, unloading valve, and pressure actuator.

resistance from the control mechanism of the turbine, the servomotor is at rest. This condition is called the "dead-beat" condition of the governor and is obtained only with a fixed position of the control valve. Without a restoring mechanism, or relay, in the speed governor, control valve and servomotor system, the speed governor can assume only one fixed position or speed. Any change above or below that speed would cause the control valve to be moved out of its dead-beat position and would cause the servomotor to keep moving the control mechanism until the speed governor had resumed normal speed. In other words, without a restoring mechanism, the governor would tend to hold constant speed irrespective of the load carried by the turbine. This would cause hunting and would also make it impossible to operate generators in parallel, because the output of each generator would transfer continually from one to the other, depending upon the quality, that is, sensitiveness and mechanical accuracy of workmanship of the governor. The restoring mechanism, or relay, therefore, has two purposes:

1. To restore the control valve to its dead-beat position, so as to stop the movement of the servomotor.
2. To allow an increment of speed change (so-called droop) for each fraction of power output of the turbine, so that for each amount of output there is a correspondingly fixed dead-beat position of the servomotor. By this means the governor can hold any desired load within the range of output of the turbine.

By adjustment of the restoring mechanism, this so-called droop can be set for any desired amount, say from one-half percent to six percent. Therefore, the speed of the unit at no-load will be one-half to six percent higher than at full load. It is evident that the greater the percentage of speed droop the less will be the tendency of the governor to hunt. In some cases it may not be permissible to allow as much as six percent. If, for example, all units in a large power system had a six percent droop, the speed or frequency of the system on heavy peak loads would be close to six percent lower than on very light loads. This undesirable condition can be corrected by individually and manually, or even automatically, shifting the restoring mechanism as the load comes on.

By introduction of a combination restoring mechanism, the relay action can first take place with a relatively large droop so as to prevent over-regulation and subsequent hunting. Then by means of a second relay mechanism the speed droop can be reduced. The time element of this readjustment or correction of speed droop can be adjusted through the use of an oil dashpot and by-pass.

• Disadvantages

Such a combination restoring mechanism introduces practical disadvantages affecting the operation of the system. First of all, it is more complicated; and second, the time element of an oil dashpot is subject to the changing behavior of the oil with temperature. Adjustment of its by-pass would accordingly be difficult.

The speed variations of a hydraulic turbine depend on two essential factors:

1. The amount of sudden load change.
2. The amount of available flywheel effect of mass rotating with the unit.

If the unit is operating by itself, that is, not connected to a large system, the sudden load changes may amount to a large percentage of its rated capacity. At the same time there may be practically no additional mass rotating with it, especially when

on a water rheostat load test. These conditions will produce relatively high sudden speed changes, tending to cause hunting, unless a relatively large speed droop is allowed by the first restoring mechanism and a relatively long time is permitted before correction to the second speed setting is effected.

• Parallel operation

If the unit operates in parallel with a large power system, then sudden load changes in that system constitute a relatively moderate percentage of the total load carried. Likewise the total available rotating mass of the system constitutes liberal flywheel effect, and therefore the speed change resulting from a load change is gradual. It is evident that the prime mover units of such a system are not called upon for as heavy a duty of regulation as in cases involving isolated prime mover plants.

The effect of the amount of speed droop on the operation of the turbine unit may well be illustrated by a few actual figures. Assume a system of 100,000 kw having an ultimate speed droop of one percent. A sudden load change of 10,000 kw, or 10 percent of the total system load, would in this case be taken care of with a change of droop of only one-tenth of one percent in the prime mover units. If the system were supplied by five units of 20,000 kw each, each unit would have to throw off 2000 kw, or 10 percent of its output, with a droop change of only one-tenth of one percent. If now the speed governor has a sensitivity of 1/50 of one percent it would not complete its action for an interval corresponding to one-fifth of the required speed change, which expressed in kw load is one-fifth of 2000, or 400 kw. It can be seen, therefore, that sensitivity of a turbine governor is of primary importance.

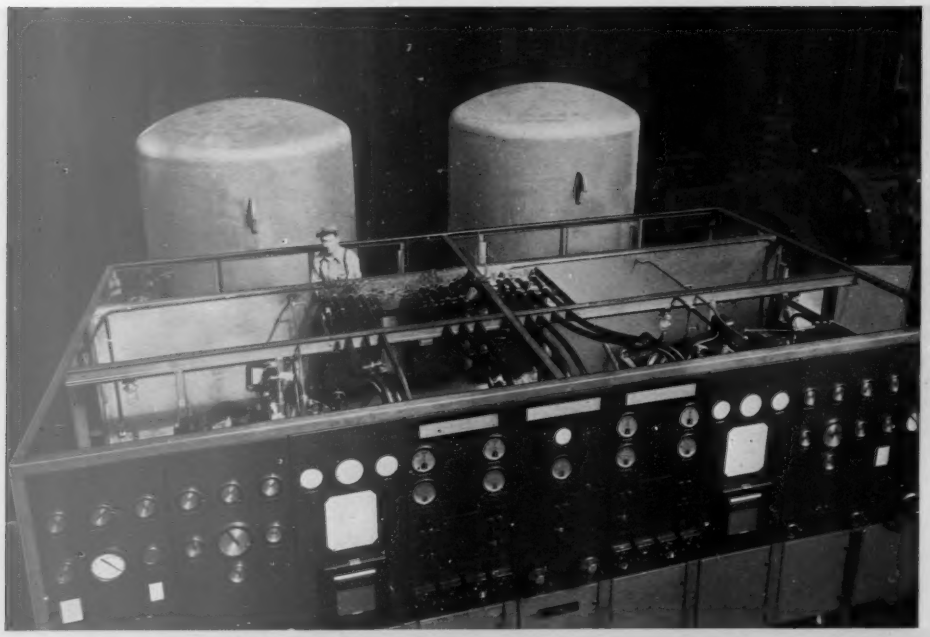
Paralleling with relatively small initial flywheel effect is often difficult because of the tendency of the governor to hunt. This condition can be greatly improved by refraining from paralleling with the synchronizer adjusting the relay mechanism, which permits the governor to close as well as open the turbine control mechanism while hunting, and instead, as has been the practice in power plants for many years past, paralleling either by hand or remotely with a load limiting device. This prevents excessive opening of the control mechanism of the turbine during the process of securing synchronism with the system.

The introduction of the electric clock operated from large power systems necessitates a very close adherence to rated frequency. This is accomplished with auxiliary frequency control devices. It is evident that so long as the prime mover units are regulated with a relatively large droop these auxiliaries are called upon to do considerable correcting when large load variations are experienced.

Hydraulic turbines answer the demand for quick response in the prime mover, except where long pipe lines are involved, which introduce problems of change of kinetic energy. Such problems are particularly acute where water cannot be wasted during the process of regulation.

Existing hydro plants have taken over severe duties, such as have been outlined, after their governors have been remodeled to specifically meet these exacting requirements. Many interesting features have been developed for this purpose and have opened a new field of activity in that particular branch of governor design and construction.

Hydraulic turbine governors of recent design, with an initial sensitivity of better than 1/100 percent and with the relay compensating mechanism holding the total full load-no-load speed droop down to less than one-half of one percent, are now in successful commercial use.



SHOP ASSEMBLY of governing equipment for two Kaplan type propeller turbines. Each governor has a rated capacity of 630,000 foot pounds.

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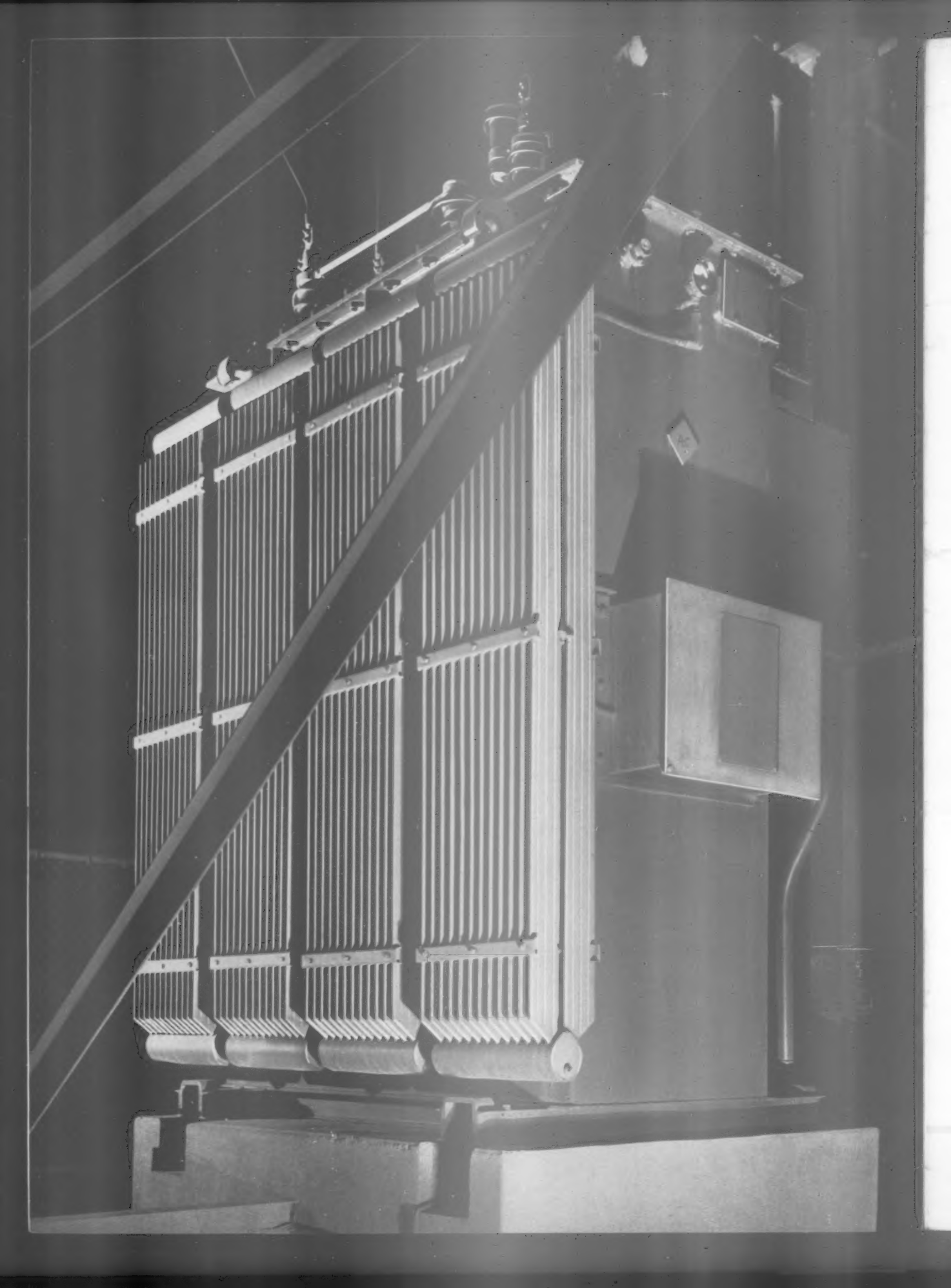

INTERPHASE TRANSFORMERS FOR MERCURY ARC RECTIFIERS

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I. K. Dortort

RECTIFIER DIVISION

ALLIS-CHALMERS MANUFACTURING CO.

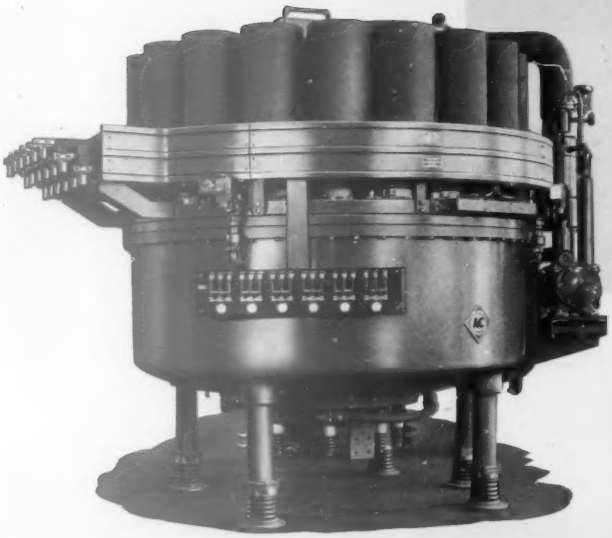

Fig. 1—GRID CONTROLLED Mercury Arc Power Rectifier built for heavy-duty subway service.

Although many people are familiar with the purpose of the piece of apparatus known as the "interphase transformer," formerly called an "absorption reactance coil" and used with mercury arc rectifiers, how it functions is not so generally understood. The name "interphase transformer" is undoubtedly even more misleading than the now obsolete term "absorption reactance coil." In the ordinary sense, an interphase transformer is not a transformer, nor is it an absorption reactance coil, any more than is any other reactor which is used to limit the value of an alternating current.

A more descriptive, though cumbersome, designation would be "selective commutating reactor." As this expression implies, the interphase transformer selectively introduces additional commutating reactance between the phases of the rectifier transformer in such a way as to greatly decrease the commutating current between certain anodes. To explain clearly how this action is accomplished, it is necessary to give a resumé of the operation of a rectifier and its transformer, the commutation of current between anodes, and the effects of the reactance on the commutation of current and on the regulation of the rectifier unit.

AT LEFT: Automatic Feeder Voltage Regulator installed in a substation of a large midwestern utility.

• Angle of overlap

The d-c output voltage of a rectifier can be considered as the positive envelope of the anode voltages, because the current is carried at any instant by that anode (or anodes) which has (or have) the highest positive potential at that moment. It will be seen that, in the case of the simple six-phase rectifier transformer illustrated in Fig. 4, anode 1 will carry current for 60 electrical degrees until its voltage falls below that of anode 2, at which time anode 2 will take the load and carry it for 60 degrees and transfer it to anode 3, and so on.

In an actual transformer this transfer of current cannot take place instantly because of the leakage reactance of the transformer windings. For example, the current will decrease in phase 1 and increase in phase 2 until phase 2 is carrying the entire load. This transition period is known as the commutating period, or angle of overlap.

When considering this condition mathematically, it is expedient to consider a commutating current superimposed on the normal currents of anode 1 and anode 2 and circulating between these two anodes. In order to carry current simultaneously, the two anodes must have the same potential, which is obtained through the short-circuit current formed by the arc between these anodes and is limited only by the impedance of the transformer windings. This is analogous to the commu-

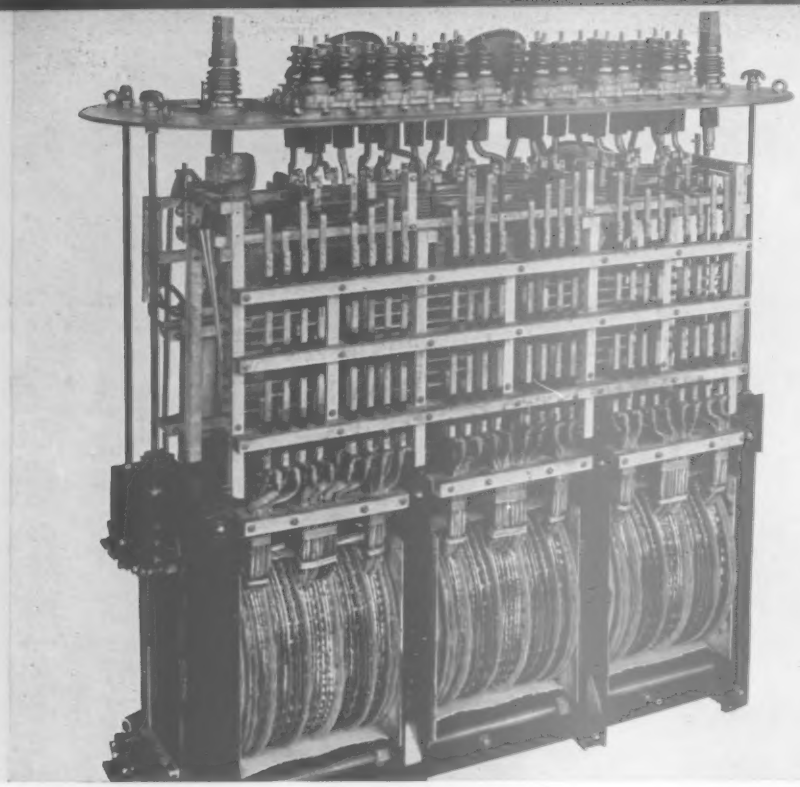

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Fig. 2 — Low voltage side of 2750 kw Rectifier Transformer with interphase unit mounted over main core behind bus-bars. BELOW: (Left front)—Rectifier Interphase Transformer; (Right)—Triplen-Harmonic Transformer; (Rear)—Main Rectifier Transformer for use with 3,000 kw rectifier.

tation of current between the windings of a d-c machine when the brush moves from one commutator bar to the next. In a rectifier, the mercury arc replaces the brush.

By referring to Fig. 5 and neglecting resistance, it is obvious that the commutating current can be expressed as

$$(1) \qquad \dot{I}_c = \frac{(\dot{E}_2 - \dot{E}_1)}{2jx} = I_c \angle -90$$

This leads to the relation

$$(2) \qquad \cos \mu = 1 - \frac{IX}{\sqrt{2}\, E \sin \frac{\pi}{p}}$$

in which μ is the angle of overlap, p is the number of secondary phases, and E is the no-load rms phase to neutral voltage.

The average d-c voltage, neglecting all losses, is

$$(3) \qquad E_d = \frac{E\sqrt{2} \sin \frac{\pi}{p}}{\frac{\pi}{p}} \times \frac{1+\cos \mu}{2}$$

$$\text{or} \qquad \frac{E\sqrt{2} \sin \frac{\pi}{p} \cos^2 \frac{\mu}{2}}{\frac{\pi}{p}}$$

Then substituting for cos μ from equation (2), it is found that

$$(4) \qquad E_d = \frac{E\sqrt{2} \sin \frac{\pi}{p}}{\frac{\pi}{p}} - \frac{IX}{\frac{2\pi}{p}}$$

which demonstrates the important fact that the voltage drop as the load increases is a linear function of the d-c current.

During the overlap the two anodes assume a potential midway between the induced phase voltages; because when the reactances in the commutating phases are equal, the drop produced across the leakage reactances by the commutating current naturally raises the voltage of anode 1 and lowers that of anode 2 by an equal amount.

It follows that, without an interphase trans-

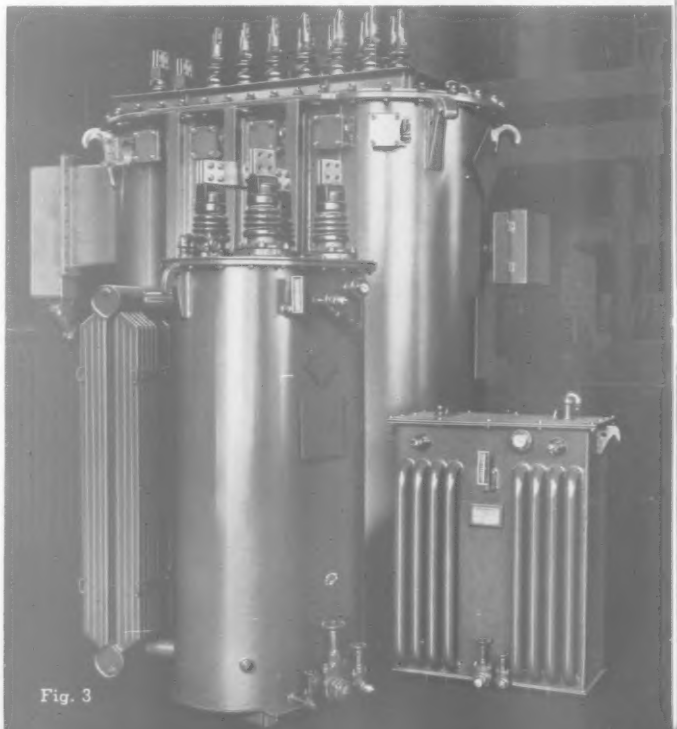


Fig. 3

former, each anode in a six-phase system carries the current 60 electrical degrees plus the angle of overlap μ. At no load the voltage is

$$E_d = \frac{\sqrt{2}\ E \sin\frac{\pi}{p}}{\frac{\pi}{p}} = \sqrt{2}\ E \times \frac{3}{\pi} = 1.35\ E$$

As the number of phases is increased, the working period of each phase decreases and the d-c voltage increases. For instance, a 12-phase connection gives a d-c voltage of 1.40 times the phase voltage, and each anode carries current 30 degrees. A single phase, full wave rectifier has a theoretical d-c voltage of only 0.9 times the phase voltage, but each anode carries current 180 degrees.

Increasing the ratio of d-c to a-c voltage will then tend to increase the utilization of the transformer, whereas shortening the working period of the anode increases the ratio of the rms to the average value of the anode current, and, therefore, decreases the utilization of the transformer. Of all practical systems, a simple three-phase system permits the greatest utilization of the transformer secondary. The mathematical optimum is a system which satisfies the relation

$$\text{(5)} \qquad \text{Tan}\frac{\pi}{p} = \frac{2\pi}{p} \text{ or } p = 2.7$$

The simple three-phase system, however, gives rise to d-c saturation of the transformer core. It also even introduces harmonics in the primary current and a large ripple in the d-c voltage. In order to overcome these objections, it is necessary to make the number of secondary phases an even multiple of the primary phases. To accomplish this and still retain the advantages of the three-phase system, it is customary to use six or 12-phase secondaries segregated into three-phase groups. The interphase transformer is used to accomplish this segregation.

Fig. 6 (a) shows the common six-phase-with interphase-phase connection. It can be seen that the interphase transformer is really a mid-tapped choke coil inserted in the path of the commutating current. If the interphase transformer is short circuited, the connection is as shown in Fig. 4. The current will be commutated from anode 1 to anode 2, from anode 2 to anode 3, and so on. The current at 0 will flow alternately toward 0′ and 0″, that is toward the anode which is firing at the moment. Now consider the short circuit removed and the current continuing to flow as before. The resultant magnetomotive force in the core of the interphase transformer is the sum of the ampere-turns produced by the currents shown in Fig. 6 (b) and is alternating in character, as the d-c components cancel each other. The a-c components of the currents are, therefore, limited by the reactance of the interphase transformer, while the d-c components are not affected.

It will be seen that the magnetomotive force has a principal frequency of three times the supply frequency, with components consisting of all odd multiples of the triple frequency.

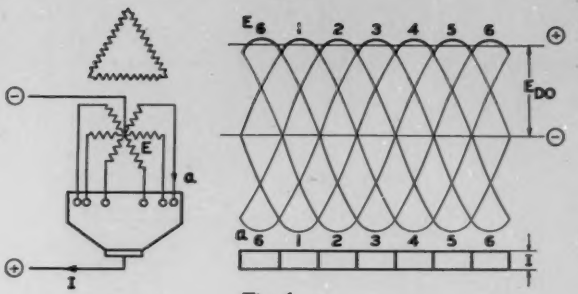


Fig. 4

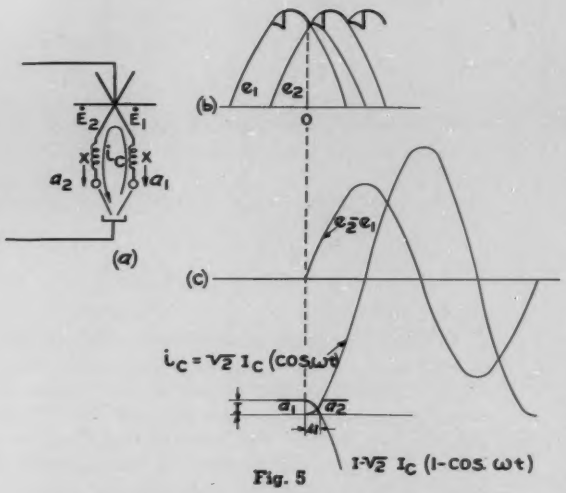


Fig. 5

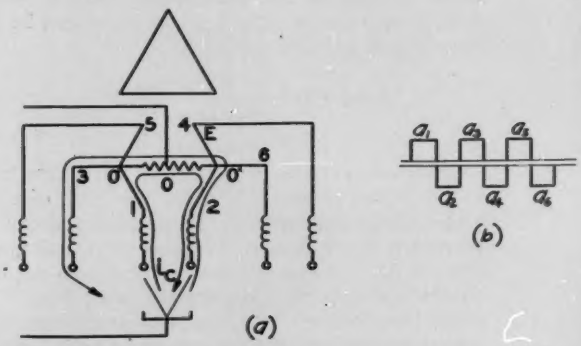


Fig. 6

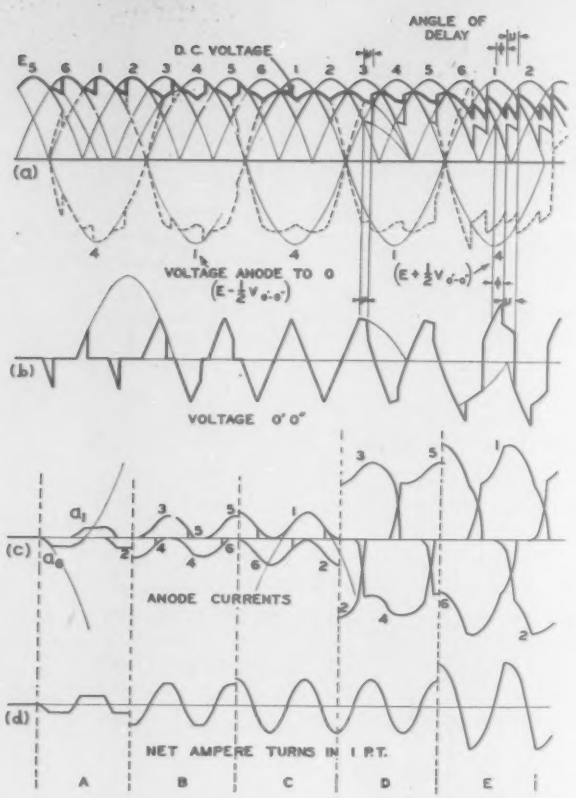


Fig. 7

When this circuit is examined under conditions of very light load, the commutating current between anodes 1 and 2 is seen to flow in the reverse direction through phase 1, then through the interphase transformer, and in the forward direction through phase 2. When the current is commutated from anode 2 to anode 3, the commutating current will flow through the interphase transformer in the reverse direction.

Because an interphase transformer or reactor has a very high impedance and, therefore, permits only a small commutating current, it will take longer to complete the transfer of current from anode 1 to anode 2, that is, the overlapping period will be quite long, even at very light loads, as can be seen from Fig. 5 (c) and the equation

$$\cos \mu = 1 - \frac{IX}{\sqrt{2}\ E \sin \frac{\pi}{p}}$$

In this respect the effect of the interphase transformer seems to be no different from that of a very high leakage reactance in the rectifier transformer. However, there is one difference: the leakage reactance drop in one secondary phase has no effect on the voltages of windings on other legs of the main transformer; whereas, an interphase transformer causes half the voltage to be added equally and simultaneously to the voltages 1, 3, and 5, and one-half of the voltage to be subtracted from the voltages of anodes 2, 4, and 6. The direction of this voltage is, of course, reversed every sixth of a cycle.

When the load current has increased to the point where the overlapping period of phases 1 and 2 extends 30 degrees, the voltage of phase 3 is raised sufficiently by the interphase transformer so that it acquires the same voltage as phases 1 and 2 and hence is able to pick up current 30 degrees ahead of its normal intersection with phase 2.

At this point then, commutation takes place between anodes 1 and 3, and for a short interval three anodes are carrying current simultaneously. In normal designs the reactance of the interphase transformer is very much greater than the leakage reactance of the main transformer; therefore, the commutation of current between anodes 1 and 3 is practically independent of the interphase transformer and takes place so rapidly at the light loads being considered now, that its effect on regulation is negligible. This does not hold true, however, when the reactance of the interphase transformer is purposely lowered, as in certain schemes of compounding.

• Pre-ignition

Figure 7 (c), Section A, shows the anode currents as they are with less load than required to cause two anodes to overlap 30 degrees, and, Section B with just about enough load to cause these two anodes to pick up 30 degrees before the normal intersection of the phase voltages. Fig 7 (a) shows the anode voltages with respect to the negative terminal or mid-point of the interphase transformer, and (b), the voltage across the full winding of the interphase transformer.

It will be noticed that in Section B of these figures the current of each anode drops back to zero almost as soon as it has picked up, and it does not pick up again until the normal intersection of the phase voltages. As the load increases, the pre-ignition period of each anode increases until it carries current continuously from the time it takes the current from the preceding anode in its three-phase system until it is commutated to the next anode in the same system.

The simplified sketch of Fig. 7 serves to illustrate the operation of the interphase transformer on the basis of commutating currents, but it also introduces an apparent paradox. While Fig. 6 (a) shows the commutating current flowing from anode 2 to anode 3, which naturally commences as soon as anode 3 has picked up, Fig. 7 (c) shows the currents of new anodes decreasing and that of the firing anodes increasing at this time.

By observing Section C of Fig. 7 (c) closely it will be seen that, although the current wave of anode 1 appears to be uniform, there is a discontinuity at the point where anode 2 picks up. Be-

fore that point is reached, the wave is the top segment of a sine wave of one polarity, and immediately afterward it is a similar segment of a sine wave of opposite polarity. The explanation is readily found by converting equation (1) to its differential form, choosing the proper subscripts, and giving the constants of integration due consideration.

Because commutating currents are always segments of sine waves of the fundamental frequency, plus a transient, which can usually be considered as direct current, and because the reactance and the commutating voltage do not change, it follows that the amplitude of the fundamental a-c component of the commutating current does not change with changes in load. What does change is the length of the segment of the sine wave which is utilized.

In the connection used in the illustration, the commutation between two anodes on opposite ends of the interphase transformer may be considered as limited to 60 degrees, since beyond that point one of these anodes drops out and is replaced by another. When the load exceeds the value required to attain this overlap, frequently referred to as the "critical load,"* the d-c component of the currents in each half of the interphase transformer increases, but the a-c components, or "magnetizing current," does not. The d-c components in the two halves oppose each other, and their resultant magneto-motive force is zero; whereas, the magneto-motive forces of the a-c components add up, and, as can be seen from Fig. 7, their frequency is three times the fundamental.

Thus the interphase transformer absorbs the difference between the output voltages of the two three-phase systems so that each system is effectually operating independently of the other, and the average d-c voltage is that of a three-phase system even though the ripple is that of a six-phase system. In other words, the output voltage of the unit is the average of the voltages of the two three-phase systems, and the difference between them is the difference between the positive envelopes of $E_1E_2E_3$ and $E_2E_4E_6$, which, being an alternating voltage, is taken up by the interphase transformer. The origin of the name "absorption reactance coil," which has been used, is therefore evident.

• Regulation below critical load

During the transition from no-load up to the critical load, a small increase in current causes a very large decrease in the average d-c voltage, giving a very steep regulation curve, as can be seen in Fig. 8. Neglecting the leakage reactance of the transformer, the voltage in this region is given by the equation

$$(6) \qquad V=\frac{\sqrt{2}\ E \sin\frac{\pi}{p}}{\frac{\pi}{p}} - \frac{IX_{IPT}}{\frac{12\pi}{p}}$$

in which p is the total number of phases, in this case six, and X_{IPT} is the total reactance of the interphase transformer at three times the fundamental frequency.

• Regulation above critical load

At loads which cause the two three-phase groups to act independently of each other, the interphase transformer no longer has any effect on the regulation, because the commutating current does not increase with an increase in load and the maximum overlap has already been achieved. Commutation then takes place between anodes 1, 3, and 5 consecutively in one group and 2, 4, and 6 consecutively in the other group. The regulation is determined entirely by the leakage reactance of the main transformer phases. It is obtained from equation (4) in which p, however, is now the number of phases in each independent system, and I is the d-c current in each system; or, by using the old designation for the case of $n\frac{1}{n}p$ phase systems isolated from each other by a suitable number of interphase transformers, the equation is

$$(7) \qquad E_d=\frac{E\sqrt{2}\ \sin n\frac{\pi}{p}}{n\frac{\pi}{p}} - \frac{IX}{2n^2\frac{\pi}{p}}$$

• No-load rise of voltage

It is evident that the regulation curve of a rectifier operating with an interphase transformer consists of two straight lines intersecting at a point very close to no-load and generally called the crit-

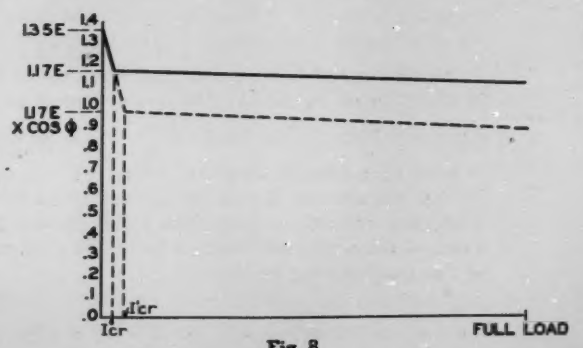
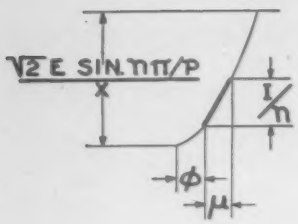


Fig. 8

* For details concerning the transition from no-load to a load greater than the critical load, see Fig. 59, p. 134, of the book "Mercury Arc Power Rectifiers" by O. K. Marti and H. Winograd.



$$I/n = [(\cos\phi - \cos(\phi+\mu)]\frac{\sqrt{2}\,E\,\sin n\pi/p}{X}$$

Fig. 9

ical load. In the case of a six-phase-with-interphase-transformer connection, the first line intersects the ordinate at 1.35 E, and the projection of the other line intersects the ordinate at 1.17 E. If the load should drop below the critical load, the d-c voltage will rise sharply, following the first sector of the regulation curve, and will reach a value at no-load approximately 15 percent higher than the voltage at the critical load. With other connections, this rise may be as much as 50 percent.

In some applications it is necessary to keep this critical load as low as possible to prevent this overvoltage on the d-c system at exceedingly light loads. Generally there is no difficulty in keeping the critical load below two percent of the rated current. When it is necessary to design the interphase transformer to meet guarantees of small critical loads, an approximation can be made by calculating the reactance of the interphase transformer for a sinusoidal voltage wave having a frequency equal to the main frequency of the interphase transformer (three times the primary frequency) and a peak voltage the same as its peak ($\frac{1}{2}\sqrt{2}$ E). Two times the peak value of the magnetizing current obtained at this voltage is roughly the value of the critical load. For most applications this is sufficiently accurate.

If greater accuracy is desirable, the wave shape of the voltage and the wave shape of the commutating current through the interphase transformer should be taken into account. This commutating current is generally called the magnetizing current, probably because it is consistent with the generally accepted name interphase transformer.

As was noted before, this commutating current is made up of segments of cosine waves of supply frequency between the limits $\pm\frac{\pi}{p}$. The critical load is reached when the anode currents of Fig. 7 (c) become continuous waves, as shown in Section C. The load current is then just equal to the peak value of the anode currents, or twice the peak value of the magnetizing current.

The voltage across the outside terminals of the interphase transformer at no-load is almost triangular in form and has an rms value of 0.416 E and a value of 0.402 E by flux voltmeter measurement. It is interesting to note that the critical load is

(8) $\qquad I_{cr} = 2 \times I_{m\,(max)}$ or $2\sqrt{2}\ I_m$

I_{cr} represents the critical load and I_m, the rms value of the magnetizing current measured with a sinusoidal voltage reading 0.402 E on a flux voltmeter.

• Losses in an interphase transformer

Another interesting feature of interphase transformer design is the method of calculating and measuring losses. In the past, the standard practice has been to apply a sinusoidal voltage of triple frequency with a peak value equal to the peak of the interphase transformer voltage. In the connection described this peak value is one-half the peak of the phase voltage, and the rms value of the voltage used for measuring the losses is, therefore, one-half the rms phase voltage. The core loss obtained in this manner is considered constant regardless of load.

Although the results are very approximate, this method is entirely sufficient in many cases for efficiency computations and guarantees, because without voltage control the core loss in the interphase transformer is merely of the order of 0.02 percent of the total input. Even at full load it approaches only 0.1 percent. However, in design problems where accurate determination of the losses is important, as in cases involving large degrees of voltage control, it is necessary to make corrections for wave shape.

The wave shape of the voltage across the interphase transformer, of course, varies considerably as the angle of overlap increases due to increasing load. An even greater change takes place when the firing of the anodes is delayed for the purpose of voltage control.

It is common knowledge that hysteresis losses in iron are more nearly dependent on the average value of a voltage wave (measured between two zero values of the voltage wave which are 180 degrees apart) than on the rms value of this wave. The eddy current losses in iron are more nearly proportional to the rms value. The flux voltmeter is an instrument which measures the average value of a voltage wave and consists of a small, full-wave rectifier connected to the voltage source and to a D'Arsonval type voltmeter. The scale of the instrument is calibrated to read directly the rms value of a sinusoidal wave having the same average value as the wave being measured. For voltage waves closely approximating a sine wave, it is then sufficient to measure the core losses at rated voltage measured with a flux voltmeter.

If it is desired to compute the loss at a voltage which is greatly distorted and not readily reproducible for a test, the following correction must be made in measuring the core loss with a sinusoidal voltage:

(9) True watts=

$$\text{Observed watts} \times \frac{\%\ \text{Hysteresis} + \%\ \text{Eddy} \times K}{100}$$

in which $K=\left(\frac{\text{rms of distorted wave}}{\text{Average of distorted wave} \times 1.11}\right)^2$

$$=\left(\frac{\text{rms}}{\text{Flux VM}}\right)^2$$

The average value of the voltage across the interphase transformer can be expressed by the following set of equations in which μ is the angle of overlap, ϕ is the angle of delay, and E is the secondary phase voltage of the transformer:

(10)

$\phi+\mu<30$: V (Average)=

$$3\left[1-\frac{\sqrt{3}}{4}\left[\cos(\phi+\mu)+\cos\phi\right]\right]E$$

(11)

$30<\phi+\mu<90,\ \mu<60$: V (Average)=

$$\frac{3}{2}\left[\frac{1}{2}\sqrt{3}\left[\cos(\phi+\mu)-\cos\phi\right]+\sin(\phi+\mu)\right]E$$

(12)

$30<\phi+\mu<90,\ \mu>60$: V (Average)=

$$\frac{3}{4}\left[\sqrt{3}\cos\phi-\sin(\phi+\mu)\right]\ E$$

The rms values of the voltage are expressed in the following set of equations:

(13)

$0<\phi+\mu<90,\ \mu<60$: V (rms)=

$$\frac{3}{2}\sqrt{\frac{1}{\pi}\left[\frac{1}{2}\left\{\sin 2(\phi+\mu)-\sin 2\phi\right\}-\frac{1}{\sqrt{3}}\left\{\cos 2(\phi+\mu)+\cos 2\phi\right\}+\frac{\pi}{180}(80-\mu)\right]}\times E$$

(14)

$0<\phi+\mu<90,\ \mu>60$: V (rms)=

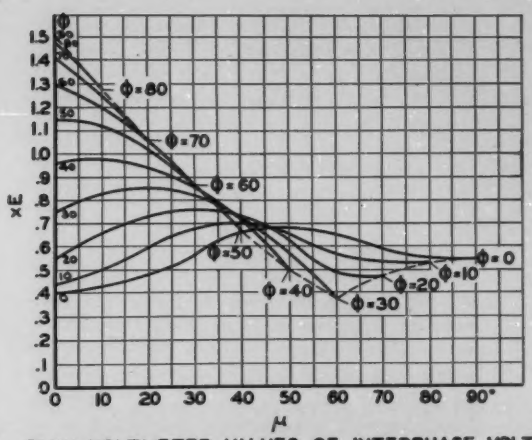
$$\frac{1}{2}\sqrt{\frac{3\sqrt{3}}{2\pi}\left[\cos 2(\phi+\mu)+\cos 2\phi\right]+1}\times E$$

These voltages are plotted in Figs. 10 and 11 against μ for various angles of delay, ϕ. Factor K is plotted in Fig. 12.

• Determination of ϕ and μ

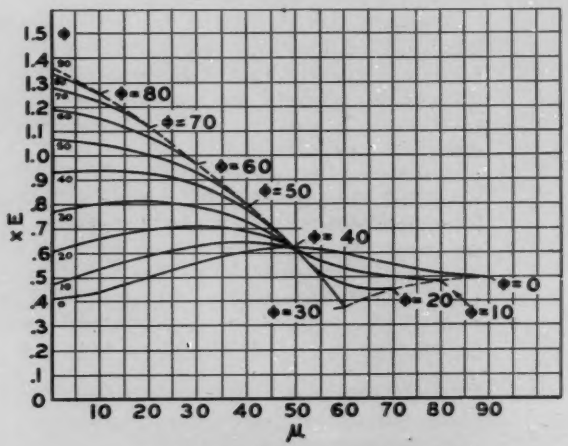
Equation (2) may be restated as

$$1-\cos\mu=\frac{IX}{\sqrt{2}\ E\sin\frac{\pi}{p}}$$



FLUX-VOLTMETER VALUES OF INTERPHASE VOLTAGE AGAINST ANGLE OF OVERLAP

Fig. 10



RMS VALUES OF INTERPHASE VOLTAGE AGAINST ANGLE OF OVERLAP

Fig. 11

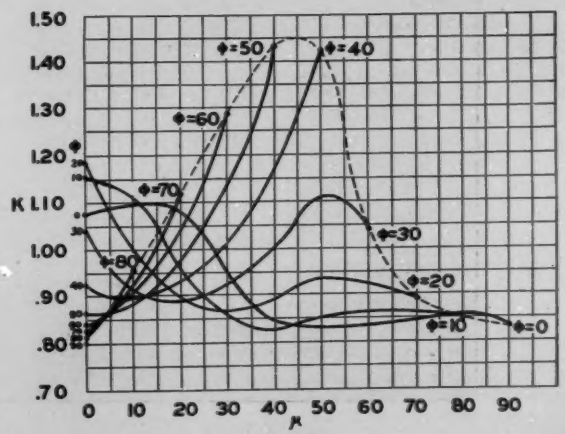


Fig. 12

If the firing of the anodes is delayed by the angle ϕ, the following equation (from Fig. 9) is obtained:

(15)

$$\cos\phi - \cos(\phi+\mu) = \frac{IX}{\sqrt{2}\ E \sin\frac{\pi}{p}}$$

The angle of delay, ϕ, lowers the d-c voltage by $E_{D0}(1-\cos\phi)$, E_{D0} being the theoretical no-load d-c voltage (in this case, 1.17 E). This reduction of voltage is independent of load, and the regulation curve is, therefore, lowered parallel to itself. The steep part of the regulating curve near no-load is not altered unless the firing of the anodes is delayed beyond the normal intersection of the phase voltages. Otherwise, this section of the curve will be projected downward to a new intersection with the main regulation curve. This intersection marks the new critical load for the given angle of delay.

• Other possible connections

Although, for simplicity, the data given have been confined principally to a six-phase system with a single interphase transformer separated into two three-phase systems, the use of the interphase transformer is not limited to this connection, as there are numerous possible connections.* A six-phase system may be separated into three single-phase full wave systems by means of a three-phase interphase transformer. A 12-phase system may be separated into four three-phase systems with a Greek-cross connected interphase transformer; divided into three four-phase systems; or split into two six-phase systems with one interphase transformer, and each of these systems may in turn be split into two three-phase systems with additional interphase transformers.

• Advantages afforded

The improvements to rectifier operation afforded by the inclusion of interphase transformers depend upon the natures of the specific application. As the d-c voltage is increased, particularly when a large range of voltage control by delayed firing is involved, the advantages of the interphase transformer diminish, and in some cases will even be over-shadowed by unfavorable characteristics.

One misconception in particular needs to be dispelled: the interphase transformer must not be depended upon to balance the load on groups of phases which tend to be unbalanced because of unequal leakage reactances. It is actually only a reactor, and as such can affect only the rate of rise, but not the steady value, of a direct current. The neutral currents from groups of phases separated by the interphase transformer are direct currents and cannot be balanced by it.

The following are the chief advantages effected by the use of the interphase transformer:

1. It improves the utilization of the rectifier.
2. By reducing the peak value of the anode current, it lowers the arc drop and improves efficiency.
3. It improves the utilization of the main transformer.
4. By reducing the amount of current being commutated at one time, it improves the regulation of the d-c voltage.

* See pp. 175-186 of the book "Mercury Arc Power Rectifiers" by O. K. Marti and H. Winograd.

TWO 2,000 KW RECTIFIER TRANSFORMERS and one 750 kva auxiliary transformer installed in a Chlorine-Caustic plant.

ENGINEERING FUNDAMENTALS

OBTAINING AND MEASURING THE VACUUM IN A MERCURY ARC RECTIFIER

There are approximately 400,000,000,000,000,000,000 molecules of air in each cubic inch at atmospheric pressure. In fact, there are so many of them that it is quite difficult for an electrical current to pass through them under ordinary conditions.

If their number is decreased to about one-millionth of the above figure, an electric current can pass through the air quite easily, especially if the remaining air is mixed with a number of molecules of mercury or some other readily ionizable vapor.

It is easy enough to make enormous numbers of mercury molecules float around in the air. This can be done by heating mercury until it boils, which it does at a temperature around 340° C. The more difficult thing to do is to reduce the number of air molecules to about one-millionth of the number generally present.

For this latter purpose, vacuum pumps have to be used. These may be of any type, from the simple cylindrical design with a moving piston or plunger to the highly refined and very efficient molecular pump. Besides these mechanical pumps, various fluids—liquids or gases—may be used to pump out the air. Water, steam, liquid mercury, and mercury vapor are four media which may be used for this purpose and which produce increasingly higher degrees of vacuum.

• Rectifier evacuation

For evacuating commercial mercury arc rectifiers of most of the types currently on the market, both mechanical and mercury vapor pumps are used. Permanently evacuated, sealed-off rectifiers, of course, do not require continuous evacuation by means of vacuum pumps because, once they are sealed, they will retain their initial vacuum almost indefinitely.

Going from atmospheric pressure to the highly rarefied interior of a mercury arc rectifier, the first pump is usually a simple rotating-vane pump operating in oil. The second pump is usually a mercury vapor diffusion pump. In it, a small quantity of mercury is heated until it boils, and the resulting vapor is so directed against baffles that it drags with it the molecules of air and gas near which it passes. Those unwanted molecules are then discharged into a pipe or intermediate vessel from which the rotary pump can remove them. The mercury vapor itself is condensed and flows back into the small mercury "boiler" at the bottom of the high vacuum pump.

Once the vacuum pumps have been operating until there is almost nothing left in the rectifier—speaking relatively, that is—it becomes desirable to measure just how little air and vapor are left in the rectifier. An ordinary pressure gauge, of course, will not do. Neither for that matter will an ordinary barometer, because the pressure of the remaining air will be so little that instead of raising the mercury column in the barometer tube some 29 or 30 inches, as it does at sea level, it would raise the mercury column about 0.00004 inch above the indication given by a perfect vacuum. This is a distance about one-thousandth of the diameter of a human hair. Obviously such a small difference in the height of the mercury column could not be detected and much less measured by the naked eye. Other means must, therefore, be employed to detect and determine the exact amount of gas and vapor pressure remaining in the tank.

• Methods used

One of the oldest and simplest schemes for accomplishing this end is the use of a sort of magnifying barometer tube named, after its inventor, the McLeod gauge. By an ingenious system of interconnected glass tubes and globes, the minute amount of pressure available is made to give a greatly enlarged indication of its magnitude, so that pressures of even one-tenth of the above mentioned one-thousandth of the thickness of a human hair can be measured with accuracy.

However, any evacuated vessel contains not only so-called "perfect" gases, whose pressure and volume relationship was first enunciated by an early investigator named Robert Boyle, but also vapors which do not behave according to the simple law of the "perfect" gases. These are readily condensed at ordinary temperatures. To measure gases of this kind, which are called vapors, advantage is taken of one of their other characteristics. Properties which lend themselves to this purpose include those of thermal conductivity, electrical resistance, luminescense in electric fields of varying strengths, etc., and all of these properties, as well as some others, have been used to form the basis of commercial vacuum gauges. Some of these will be described in a later issue.

ON FOLLOWING PAGES: Assembling plate steel spiral casing on speed ring of a 20,000 hp hydraulic turbine.

BALL AND ROD MILLS AND THEIR MOTOR DRIVES

★

• E. F. Stemmler . . . MINING DIVISION
ALLIS-CHALMERS MANUFACTURING CO.

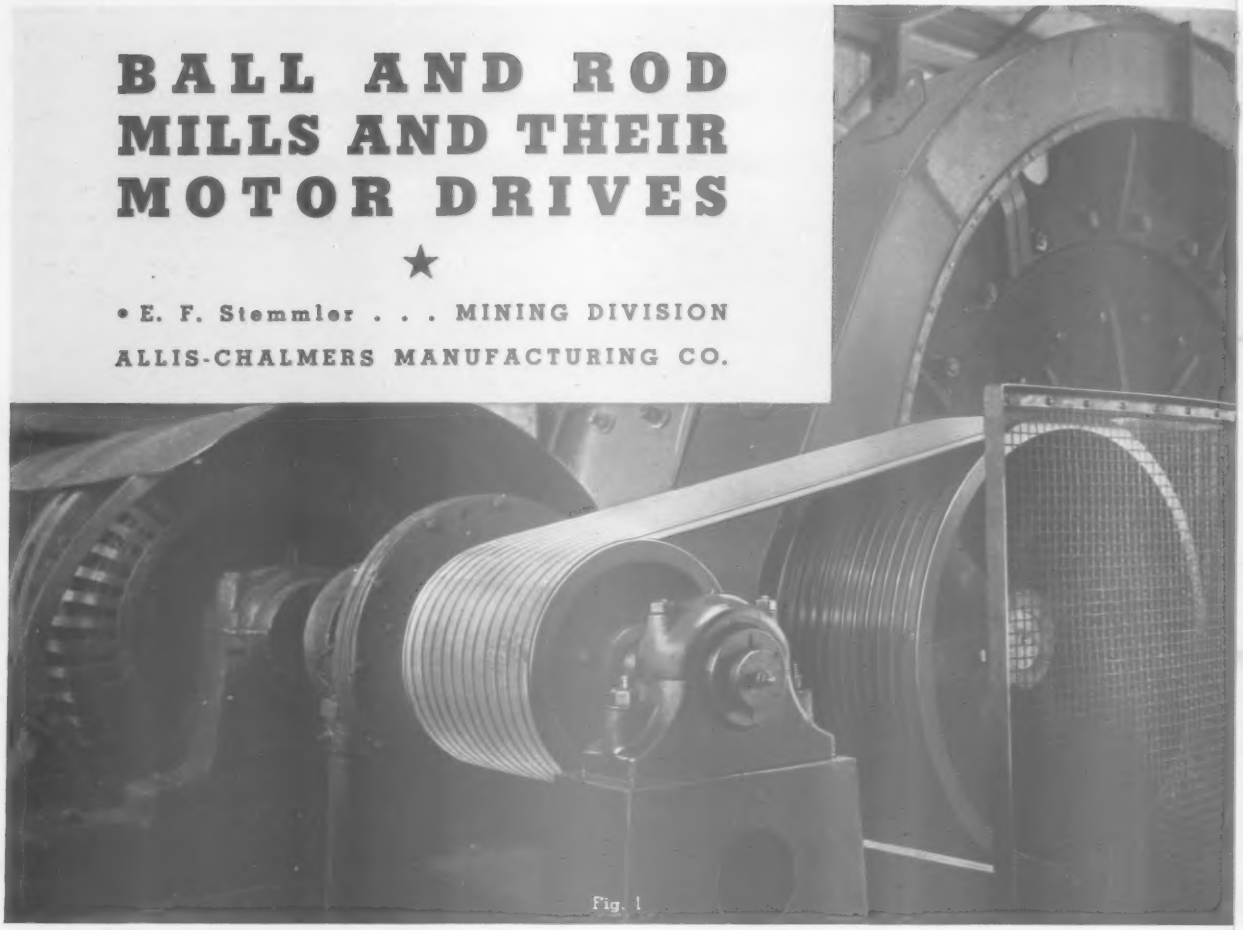


Fig. 1

In general the designs and appearances of ball mills and rod mills are very similar except for minor details. Both types of mills are used to further reduce material that has been crushed. Although their most common applications are for grinding ores in the mining industry, many uses have been found for them in connection with other materials not directly associated with the mining industry.

Despite their similarities in design and appearance, each type of unit has its characteristics which make it best suited for specific service requirements. Ball mills loaded with forged steel balls as grinding media are ordinarily used to best advantage for grinding material reduced to particles ranging in size from three-fourths of an inch and under through fine meshes, including 325 mesh. Rod mills, on the other hand, when loaded with rods, have a grinding range usually between 10 and 60 mesh. In some cases an advantage of one type of mill may overlap an advantage offered by the other type, and then, of course, a complete analysis of the problem should be made to determine the most desirable type.

A ball mill or rod mill is usually loaded with its respective grinding media to approximately the center line of the mill. This constitutes an unbalanced load and requires special consideration to the problem of starting from standstill. When the mill is up to normal speed, the load is practically constant and only slight pulsations in power requirements can be noticed.

The unbalanced load features require careful consideration in order that the proper type of motor may be selected for the type of drive decided upon. The motors may be of the single squirrel cage, double squirrel cage, wound rotor or synchronous type, depending upon the drive.

Various combinations of drives may be used with ball mills and rod mills, and the arrangements are, of course, necessarily those which are best suited to the size of unit in question, to the existing equipment, or to the plant under consideration. The sev-

eral common arrangements of drives are: spur gear with pulley and clutch, spur gear with multiple V-belt drive; herringbone gear for direct connection; and herringbone gear and speed reducer drive.

The type of drive employing a spur gear with a pulley and clutch is frequently used for the smaller sizes of ball mill and rod mill units where small capacities are involved and where all other equipment is arranged for belt drive. For these installations a standard squirrel cage motor with low starting torque may well be used, as the motor can be brought up to speed and then the clutch thrown in to start the mill from standstill and bring it to operating speed.

• V-belt

For the medium size units, the spur gear and multiple V-belt drive combination is used extensively. Fig. 1 shows a typical arrangement. The multiple V-belt drive permits very close centers and makes possible a very compact arrangement of motor and mill. Ordinarily clutches are not used with this combination; therefore, it is necessary to provide a motor having a high starting torque to start the mill from standstill. These requirements can be met by either a double squirrel cage induction motor, a wound rotor type motor, or a synchronous motor. The synchronous motor and the double squirrel cage motor, however, should be used only on systems where a large inrush of current at starting is not objectionable to the power companies. Wound rotor motors, on the other hand, are used in many cases because of their high starting torque and moderate current demand from the power circuit.

• Direct-connected

For large size units where sufficient power is available, direct-connected drives are generally preferred as shown in Fig. 2. With this type of drive it is necessary to supply a set of high ratio primary gears to permit the use of medium speed slip ring induction motors or synchronous motors. The primary gear ratio is usually from 15 or 20 to one, and this can be obtained with herringbone gears or gears of similar type.

To permit the use of high-speed motors of the wound rotor or synchronous type, a speed reducer with secondary gears enclosed in an oil-tight case is often employed.

In either of these cases, whether arranged for direct connection with primary gears only or with both a primary and a secondary gear set, high starting torque motors are essential unless special means are provided. The wound rotor type is the most desirable type for direct connection because of its ability to deliver a large starting torque with minimum current, but when power factor correction is to be considered, synchronous motors might be considered provided their larger starting current characteristics are not objectionable.

Magnetic clutches are generally used where synchronous motors having standard starting and pull-in torques are used for direct-connected drives. A motor of this type requires a magnetic clutch, since its starting torque is not sufficient to start the mill and bring it up to full load speed. In such cases, the motor is brought up to speed at no load; and when the magnetic clutch is energized, the load is brought from rest to operating speed.

If magnetic clutches are not used and a synchronous type motor is desired, the motor must, of course, be specially designed to have sufficiently high starting and pull-in torques to permit starting the mill and bringing it up to operating speed.

All synchronous motors may be built for either unit or 80 percent power factor. Because the loads of ball mills and rod mills are practically uniform and the mills operate twenty-four hours a day, seven days a week, they provide an excellent means of power factor correction.

It can be seen from the foregoing that an analysis of the application for a drive to be used in connection with a ball mill or a rod mill is very important, as the type of drive selected can have a direct influence on the successful operation of the mill.

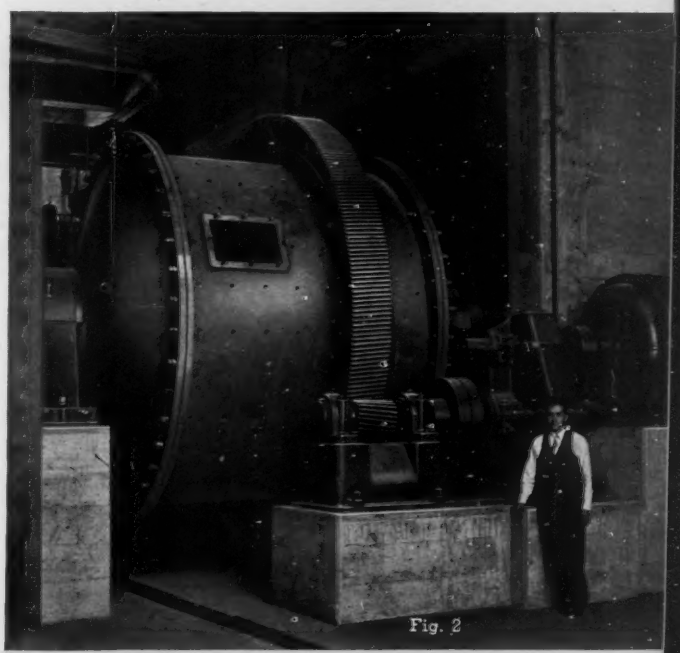
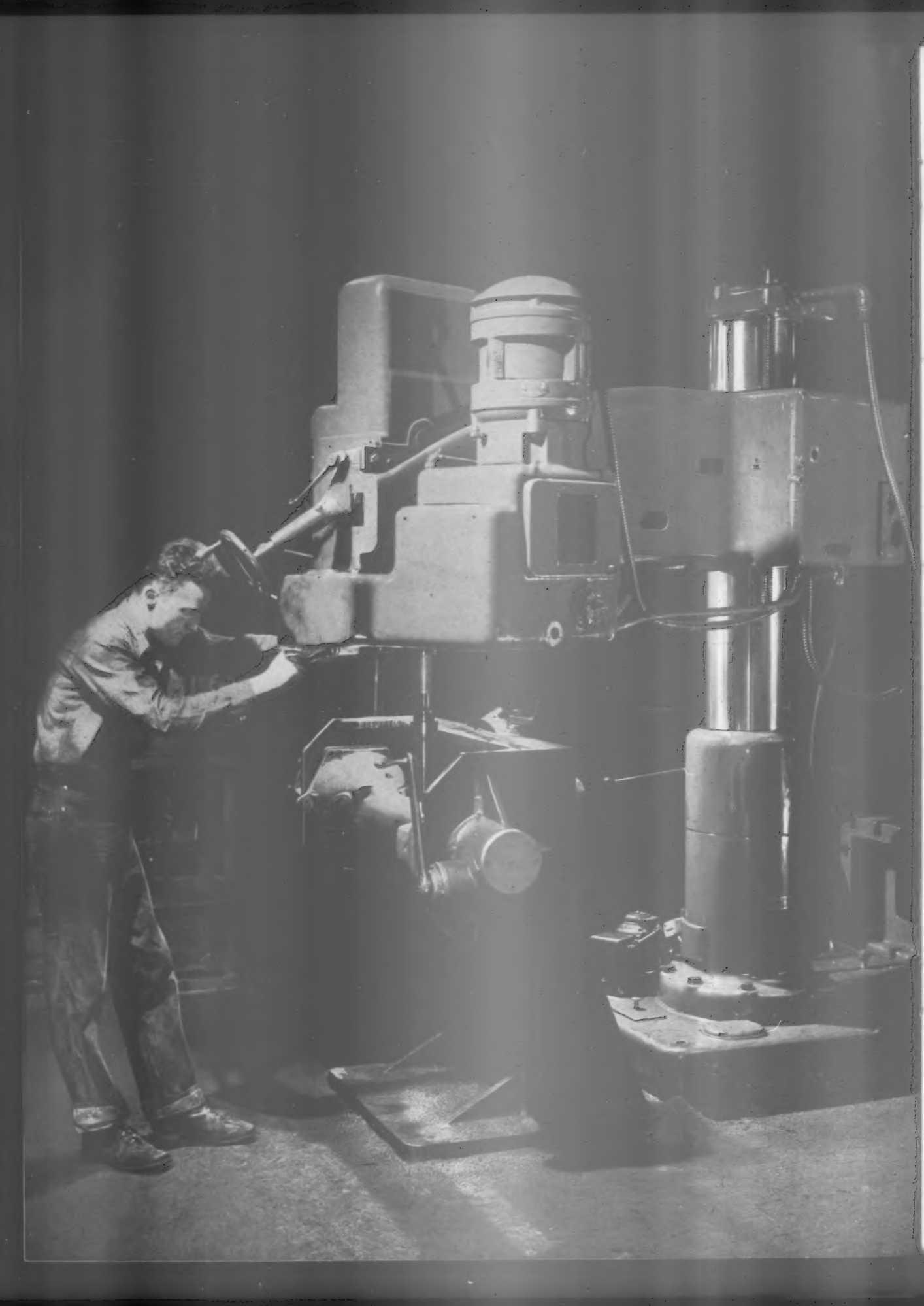


Fig. 2



AIR BLAST CIRCUIT BREAKERS

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Wm. S. Edsall, Assistant Manager
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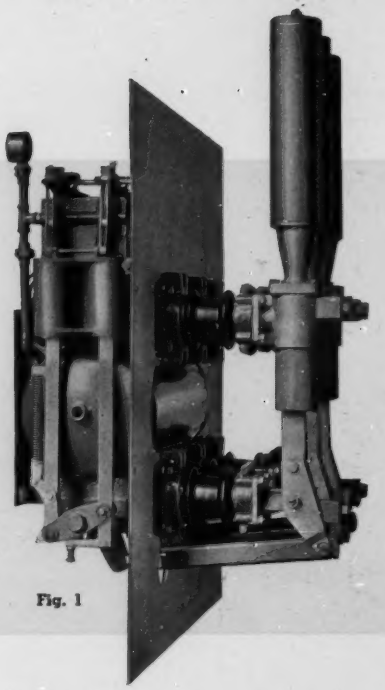


Fig. 1

European manufacturers were the first to attack the problem of producing satisfactory oilless circuit breakers. They were spurred on not only by the desire to eliminate possible hazards through the use of oil in circuit breakers, but also by the high cost of petroleum products in Europe. The natural and first step was to change the form of oil circuit breaker design to a type using a very much reduced volume of oil. Some successful circuit breakers are built in this manner today, but these are still subject to the objection that they require some oil.

Some European manufacturers have had experience with circuit breakers using water, or other non-inflammable liquids, as the interrupting medium. These breakers have not found a very wide market because the interrupting characteristics and other factors inherent to breakers of this type are not as favorable as some other oilless designs.

• Only oil and compressed air applicable to all sizes and designs

Research work has been done in which consideration has been given to many oilless circuit breakers, such as the vacuum breaker, the helium breaker, the carbon-dioxide breaker, the water circuit breaker, and the mercury arc rectifier. Work has been done on several types of compressed air and air blast breakers. Each type of circuit breaker must be measured by certain standards. These standards are: First, it must be capable of being designed for a high degree of insulation security. Second, it must be capable of carrying current continuously without undue temperature rise. Third, safe and sure interruptions must be effected. Fourth, the breaker must be capable of closing and opening and reclosing at high speed.

Measured by these standards, the present-day oil circuit breaker is more satisfactory than any oilless circuit breaker known. It is the only type of breaker to which the same medium of interruption and the same principle of interruption can be applied throughout the entire range of current, voltage, and interrupting capacity steps — from the smallest indoor breaker to the largest and highest voltage outdoor breaker. Vacuum breakers, water breakers, and other types can be applied to cover certain portions of the range, but each is limited and cannot equal the versatility of the oil circuit breaker.

Aside from oil, the medium which most nearly approaches the versatility of oil is compressed air, as applied in the air blast circuit breaker.

The application of compressed air for the extinguishment of an arc was first suggested about the beginning of the century. There had not been a great deal of progress on the air blast breakers, because sufficient interrupting capacity testing facilities were not available. With the development of high interrupting capacity testing laboratories capable of continuous rapid testing, the research work for compressed air breakers got under way. Unlike the oil circuit breaker, which started on a rule-of-thumb design basis and, later, by means of continual interrupting capacity tests, finally evolved into a scientific piece of apparatus, air blast breakers were initiated on a sound basis of research, development, and test. Thousands of short circuit tests under all voltages, rates of rise of recovery voltage, frequencies, power factors, and currents have built up a background of scientific design data, the like of which was not available in the early history of oil circuit breakers. The air blast breaker has its limitations like any other piece of equip-

AT LEFT: Induction motor driving a radial drill press.

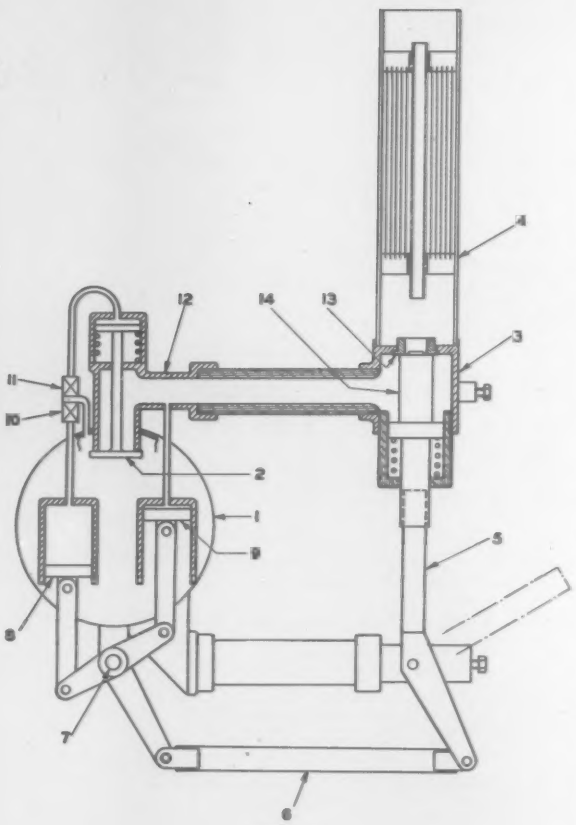


Fig. 2

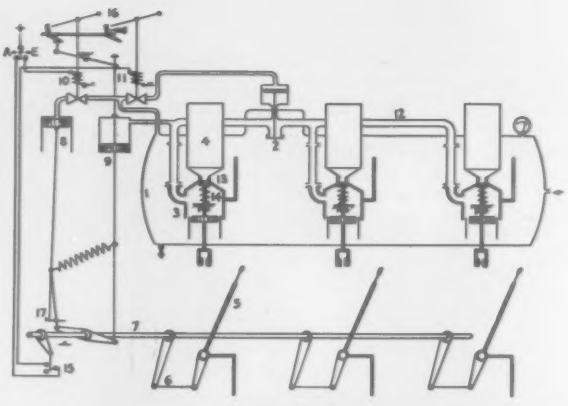


Fig. 3

ment. But, unlike other circuit breakers, the boundaries of its operating characteristics have been explored; its limitations have been found; and safety has been assured by the application of reasonable factors of safety. The air blast breaker has emerged from the test laboratories as the unique circuit breaker of today.

• Design of the air blast circuit breaker

The general design and the operation of one specific construction of the air blast circuit breaker are illustrated in Figs. 1, 2, and 3. In the diagrammatic drawings a welded steel compressed air tank (1) comprises the foundation on which the active parts are mounted. Compressed air at 120 lb. or 225 lb. is stored in sufficient volume for one interruption. The tank has pipe connections connecting it to the compressed air supply and storage system of the station. The compressed air tank is horizontally mounted, and the main air blast valve (2) is fitted onto the top of it. Hollow insulator supports secured to the tank carry the active elements of the breaker. The arcing chambers (3) are attached to the three upper insulator supports. These arcing chambers carry the exhaust mufflers or coolers (4). Isolating or disconnecting contacts (5), connected in series with the arcing chambers and mechanically interconnected, have their fulcrums on the three lower insulator supports. The operating links (6) control the disconnecting contacts and are actuated by the breaker shaft (7). Two compressed air pistons (8) and (9), governed either electrically or manually by the control valves (10) and (11), actuate the breaker shaft (7).

• Its operation

The opening of the breaker is effected by means of the air blast valve (2), which is controlled by the solenoid-operated valve (11). When valve (2) is opened, compressed air rushes through the valve into the distribution duct (12) to the three hollow upper insulator supports and through these to the arcing chambers (3). Each of the arcing chambers contains a fixed contact (13) and a movable contact (14). The movable contact is designed as a piston and is kept pressed upward by spring action against the fixed contact. As soon as the air pressure in the arcing chamber rises, this movable contact is forced downward by the compressed air. This movement is very slight—about one-half inch.

As the mass of moving contact displaced is negligible compared to the forces acting on it, the displacement or movement is extraordinarily rapid. Upon separation of the contacts, an electric arc is formed, which is driven through the fixed contact by the rush of compressed air. The air blast envelops the arc on all sides and streams along its length, sapping its energy and causing it to be extinguished in a very short space of time.

Simultaneously with the air rush to the interrupting chamber, the switching-out cylinder (9), connected to distribution pipe (12), is also subjected to air pressure. The piston of cylinder (9), acting through breaker shaft (7) and insulating link (6), causes the disconnecting contacts (5) to open. The time required for the opening of the dis-

connecting contacts is relatively long compared to that required for opening the arcing contacts and extinguishing the arc; and, therefore, the disconnecting contacts open under no current at a certain fixed time after the extinction of the arc.

An auxiliary contact (15), mounted on the shaft (7) of the breaker, interrupts the current actuating the solenoid-operated valve (11) as soon as the disconnecting contacts are open. This valve then closes, cutting off the air supply to the air blast valve (2) and, at the same time, letting the air remaining on the reverse side of the blast valve (2) stream out. The blast valve (2) then closes under the influence of the pressure of the air remaining in the compressed air tank, and this causes the pressure in the arcing chambers to fall, which is followed by the arcing contacts coming together again under the force of the spring. The air blast required to rupture the arc causes the pressure in the air tank to fall to about half its original value. As the tank is always connected to a compressed air supply, air again flows to the breaker tank, and the breaker is ready to act again.

In order to close the breaker, control valve (10) is actuated and compressed air is thereby admitted to the closing cylinder (8). The piston of this cylinder moves the disconnecting contacts through breaker shaft (7) and links (6) and causes them to close very rapidly, which closes the main circuit. Thus, the closing of the breaker always takes place in air under atmospheric pressure. Thorough tests have proved that the breaker can be safely closed on a heavy short circuit. There is practically no sparking or burning of contacts, because the high speed of travel of the contacts driven by the air pressure permits no appreciable arcing time.

By means of a simple interlock (16), all switching operations, once initiated, are carried to completion. A mechanical trip-free device (17) permits the disconnecting contacts to close against short circuits and open freely instantaneously.

The oscillogram, Fig. 4, clearly illustrates the performance of the breaker just described. This oscillogram shows the closing and opening of a 50,000 volt, high speed, air blast circuit breaker. The test was carried out at full voltage, both when closing on 745,000 kva and when rupturing at 550,000 kva. The time between closing and opening, that is, the duration of the short circuit, was intentionally chosen to be long enough to distinctly separate the oscillograms of both operations. Under ordinary service conditions, the duration of a short circuit is considerably shorter and is dependent, of course, on the setting of the protective relays.

The air blast breakers produce a rather sharp noise when interrupting. Adequate mufflers are available to reduce the intensity, but the noise is still audible for some distance. This may be desirable.

• Compressed air equipment

The usual operating pressure for air blast breakers is 120 or 225 lb. depending on the interrupting capacity. In plants where there are breakers using

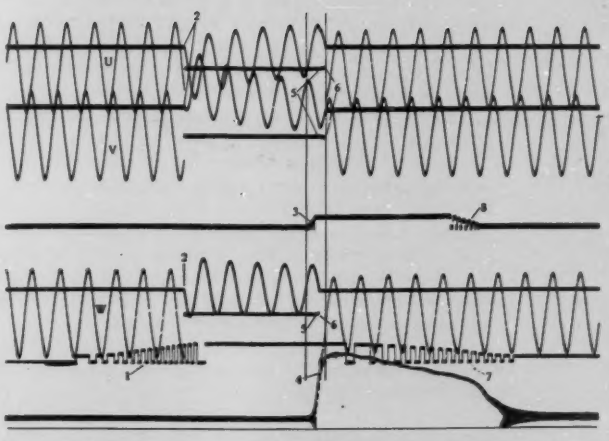
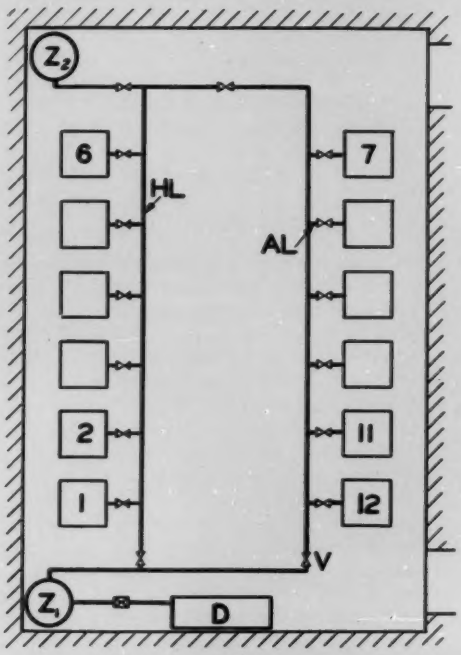


Fig. 4



1-12. AIR-BLAST HIGH-SPEED CIRCUIT BREAKERS.
D. COMPRESSED-AIR GENERATOR.
Z_1, Z_2. ADDITIONAL AIR CONTAINERS.
V. VALVE.
HL. MAIN DISTRIBUTION PIPE.
AL. BRANCH PIPE.

Fig. 5

two different air pressures, the air is compressed and stored at the higher pressure and passes through a reducing valve for use on the lower pressure. If the air pressure in the distribution plant drops because of some trouble, an alarm is sounded. The breakers on the system are not affected, as their pipe connections to the air-distribution plant have check valves. It is impossible for air to flow back from the breaker tank to the distribution system; hence, the breakers always have sufficient air for one opening and one closing operation.

Fig. 5 shows the diagrammatic layout and general arrangement of the compressed air generating and distributing plant in a station containing twelve circuit breakers. In a station of this type the storage tanks may be located in the corners, and the compressed air plant, at the end, as shown. With such a distributing system, even under the most unfavorable conditions the circuit breaker compressed air tank may be refilled to operating pressure in about five seconds. This speed of filling is attained even though the main distributing pipes are only one-inch standard pipe, and the taps from the distributing pipe to the breaker tanks, one-half inch pipe.

The compressed air supply system is quite similar to the usual storage battery system for closing and tripping oil circuit breakers. The motor driven air compressor is substituted for the charging motor generator set and regulating equipment. The storage tank acts in place of the storage battery. One-inch copper distribution pipes are used in place of the d-c control buses.

Also, the capacity of the air system is calculated on very nearly the same basis as a storage battery system. It is obvious that the sizes of compressed air plants and of the storage tanks vary with the number of circuit breakers in the stations and the probability of a large number of breakers interrupting simultaneously. The system diagrams and scheme of relaying furnish the information as to how many breakers can possibly trip at one time. With such information at hand, it is customary to select storage tanks of adequate size to permit not only the calculated operations but probably as many as twice the number. Storage-tank capacity is not expensive, and a liberal factor of safety can be economically introduced. The usual method is to have sufficient storage-tank capacity so that all of the breakers could operate twice before the air pressure in the storage tanks would be lowered to a point where it would be necessary for the air compressor to start.

Many very reliable air compressors are on the market today. Even for applications where air is stored at 25 atmospheres (350 lb. per square inch) and reducing valves are used to provide air at operating pressures, reliable equipment is obtainable. Means are provided for automatically starting the air compressor upon lowering of pressure in the storage tanks. Adequate alarms to inform the operators of any failure in the compressed air system or the distribution system are also included.

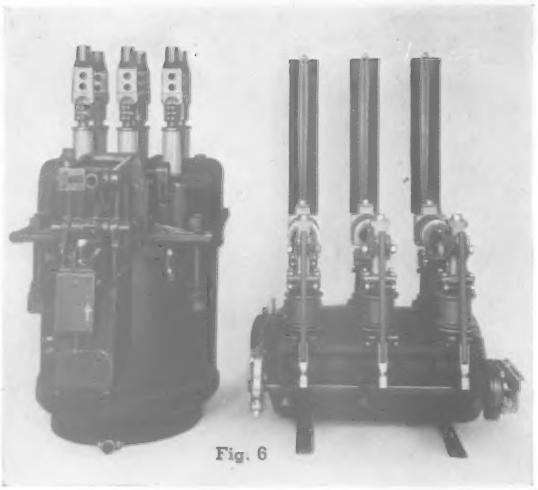


Fig. 6

Apart from the two solenoid control valves for closing and tripping the breaker — which need not necessarily be considered as parts of the breaker proper — there is only one valve in which the sealing must be perfect, and that is the main air blast valve. This is a simple and easily accessible composition valve. The compressed air pressure in the storage tank acts on the valve to secure tightness.

In this connection, tests were made on a plant similar to the one shown in Fig. 5. The pressure loss on the whole plant with all connecting cocks open measured about 3½ lb. per square inch over a period of 24 hours. With no switching operations, such a plant would go for nearly a month before the pressure would fall to such a point as to cause the air compressor to start again.

• Advantages of the air blast breaker

It can be seen that the air blast breaker merits serious consideration for the following reasons:

1—It is an oilless circuit breaker.

2—The same medium—compressed air—can be used in nearly all designs, from the lowest voltage to the highest voltage and from the lowest interrupting capacity to the highest.

3—For the same interrupting duty, the weight of an air blast breaker is less than the weight of an oil circuit breaker.

4—Interrupting speed, two to four cycles.

5—Very fast reclosing.

While the advantages mentioned above are gained from the particular design of air blast breaker described herein, they are also obtainable to some extent by the use of other known designs of air blast breakers. One outstanding design has been discussed in detail simply to clarify the operation and characteristics of the air blast type of circuit breaker. Fig. 6 shows a comparison of oil and air blast circuit breakers.

KNOW YOUR PATENTS!

• W. Zierold

PATENT ATTORNEY . . . ALLIS-CHALMERS MANUFACTURING CO.

When a man speaks of a patent as a "pioneer" patent, a "basic" patent, a "broad" patent, or modestly refers to it only as a "strong" patent, his statement will bear investigation. A correct estimate of the scope of a patent is often difficult because of the complexity of the questions involved. We have to keep in mind that the merits and demerits of a patent depend not only on engineering considerations but on legal considerations as well. For instance, a man may have made an invention of the highest rank from the standpoint of ingenuity and engineering accomplishment, and yet his patent may be worth little or nothing because it is legally inadequate or defective. On the other hand, an invention which rises only little over ordinary engineering skill may still be comparatively valuable if it is covered by a legally sound patent. Engineering and legal judgment alike are necessary to determine the merits and demerits of a patent.

To the inquisitive mind, a patent makes its strongest appeal by the disclosure of that intangible something which we call "invention." Like a work of art, an invention manifests itself by its presence, and when we are called upon to analyze an invention, we are facing about the same difficulties which an artist would have if he were to explain just what makes his creation a work of art.

Fortunately for the inventor, the patent law does not require him to explain the metaphysical character of his mental creation, but it does require him to make "a written description of his invention or discovery, and of the manner and process of making, constructing, compounding and using it, in such full, clear, concise, and exact terms as to enable any person skilled in the art or science to which it appertains, or with which it is most nearly connected, to make, construct, compound, and use the same; and in case of a machine, he shall explain the principle thereof." Between the lines of this written description which is required of the inventor, we must look for the spark of genius, for the display of originative faculty, which alone makes his disclosure an invention.

• Drawings

Patents for mechanical devices or anything that is capable of illustration speak to us not only by words but also by drawings. The language of the drawings is the inventor's most convenient means of expression; it is most readily and quickly understood by those to whom the patent is addressed. In starting an investigation of a patent, we first study the drawings. If we know enough about the art to which the patent relates, we may be able to approach the invention by a critical examination of the drawings alone. We may find a device or machine of a general character with which we are familiar, but which has certain particularities which strike us as new and original.

The invention will then most likely be found in the departure from that which we know is old and which has been disclosed by others before the inventor made his invention. It is also well to note the date of the filing of the application for a patent, which is plainly printed on the drawings. A clear drawing, skillfully prepared so as to bring home the point or points which the inventor wants to make, is a decided asset to a patent, since it affords a view of the invention which would be difficult, if not impossible, to depict by words alone.

We must be careful, however, not to mistake the physical embodiment of the invention which is illustrated in the drawings for the invention itself. The drawings reveal only certain ostensible factors of the invention from which the cardinal factors are still to be determined. In other words, the device shown in the drawings may be subject to modification and yet have the characteristic features which are the essence of the invention. A basic or broad patent will permit substantial modification of the concrete exemplification of the drawings without elimination of the invention, while a narrow or restricted patent, on the other hand, will require close adherence to the concrete exemplification of the drawings in order to let the invention survive in a modification.

• Specification

Turning next to the written language of the patent, we find that it does not start out with a description of the drawings but with a more or less lengthy discussion of the "objects" of the invention. Here the inventor states what he proposes to accomplish by his invention, and what he says and the manner in which he says it often become highly important in determining the scope of his patent. However, the statement of invention, as

the discussion of the objects is called, should not always be taken at face value. It is not unusual for a statement of invention to be written in such general terms as to be practically meaningless, or for it to be overdrawn and grossly misleading as to the invention which the patent actually covers. A weak and colorless statement of invention, as well as an overdrawn or misleading statement of invention, is a decided handicap in the interpretation of a patent.

How an overdrawn or misleading statement of invention gets into a patent is easily explained. When an inventor files his application for a patent, he proceeds on what he knows of the prior art, and he writes his statement of invention on the basis of this knowledge. The U. S. Patent Office may then cite prior patents or other references to show that the inventor was mistaken in what he thought he had invented; and when he finally gets his application allowed on what patentable surplus it may contain, he forgets or neglects to revise his statement of invention in conformity with the actual state of the prior art. Thus, we see that the statement of invention is not an infallible guide towards a correct understanding of what the patent really covers, and we would make a grave mistake by judging a patent merely on the strength of the contents of the statement of invention.

The principal purpose of the statement of invention is to give us an understanding of the utility of the invention and of its advantages which the inventor believes are his contribution to the advance of the art. Knowing that much about the invention, we come closer to the appreciation of its merits, but what the patent really covers still remains to be seen.

• Disclosure

The law requires, as we have seen, that a patent contain a full disclosure of the invention, and the discussion of the objects serves in part to comply with this requirement. In order to further comply with the requirement for a full disclosure, the specification of the patent proceeds with a description of an embodiment of the invention. Naturally, the inventor selects for exemplification in the patent the best mode he knows of for carrying out the invention. By doing so, however, he does not commit himself to a limitation in the sense that the invention may not be embodied in another or better way than that which he has selected for exemplification and which he thought was the best when he filed his application. A carefully written specification guards against the implication that the invention might be limited to the concrete exemplification by stating that the drawings show a "preferred" embodiment of the invention or by other statements of like import.

The desire to avoid undue commitments in the description of the drawings also finds expression by frequent reference to possible alternatives or substitutions. Such statements are sometimes helpful in segregating the important from the less important features of the invention, but they often cause the uninitiated reader to wonder about their possible meaning. For instance, if an inventor has included a statement that one part of his device is connected to another "by bolts or any other suitable means," we will be about ready to agree with the pungent criticism of a commentator who observed, "He may be talking about bolts but I think that the brother is nuts." Indiscriminate references to alternatives will indeed confuse rather than clarify the invention, but if judiciously used, they are no mere legal hocus-pocus and serve a real purpose in elucidating the invention.

The selected exemplification of the invention is usually described with meticulous care, it being the inventor's theory that by enlarging upon details he will be sure to catch the invention. In the case of a machine, the description of its construction and mode of operation often becomes cumbersome reading to which, however, we must submit in order to be fully equipped for a critical view of the invention.

• Claims

In addition to the requirement of a full disclosure of the invention, the patent law requires that the inventor shall "particularly point out and distinctly claim the part, improvement, or combination which he claims as his invention." In other words, the entire disclosure, including drawings, statement of invention, and description is mainly and lastly only a basis for the claim or claims which appear as one or more numbered paragraphs at the end of the specification.

The original patent document which the inventor receives from the U. S. Patent Office bears on its first page an impressively sealed statement which proclaims that the patent is to grant to the inventor, for the term of 17 years, the exclusive right to manufacture, use, and vend his invention throughout the United States and the territories thereof. In order to make it reasonably possible for any one to respect this grant and avoid infringement, the inventor must not only disclose his invention, but he must also claim it.

Let us assume that there were no claim or claims in a patent. In that case the inventor could assert his right of exclusion against supposed infringers entirely at his pleasure and in the most high-handed manner. It would leave the door open for him to change his mind from time to time about what he intends to claim as questions of infringement arose, and there would be no end to arguments about his rights.

For example, there would be those who would say that the inventor could not claim infringement unless the embodiment of the invention as it appears from the disclosure had been copied in every detail—a very disputable argument, because it must be remembered that the concrete form in which the invention has been incorporated only reflects the spirit of the invention, and that even an inven-

tion of the most limited scope is always capable of modification, at least to some extent, without becoming extinct.

Then there would be those contestants who would be willing to concede that the disclosed embodiment of the invention is capable of modification, but only within certain limits—limits which they would fix entirely to their liking and to the utter dislike of the inventor. The inventor of course would say that the invention entitled him to claim the world.

Extreme views such as these may appear unreasonable and unlikely to be taken even if patents were issued without claims since honesty and reasonable judgment may be expected on both sides, on the side of the public as well as on the side of the inventor. Be that as it may, the fact remains that a patent without claims would present the greatest difficulties to an equitable and impartial interpretation. Without expert knowledge of the art to which the patent relates, we could not even guess what the inventor might be entitled to claim, but, with the inventor's claims at hand, we can at least form an opinion as to the possible limits of his right of exclusion.

A claim is a definition of the disclosed invention, and in formulating such a definition the inventor will withdraw more or less from the embodiment of the invention which he has described. For instance, he probably will not call a spade a spade, but he will call it a soil working implement if the invention is susceptible of definition under the broader term; and he will otherwise couch the claim in general rather than specific terms.

This may make it difficult for us to understand the claim upon first reading if we have not taken a good look at the disclosure. But after we have understood the disclosure and then read the claim carefully and keep our mind fixed on the disclosure, we will see quite readily how it reads on the disclosure. The mystery which at first seemed to surround the claim will quickly vanish, and the invention defined by the claim will—or should—come to light. Before any claim is allowed it must pass the criticism of the examiners in the Patent Office, who consistently refuse to allow claims which they consider vague, ambiguous, or indefinite. Rejections on these grounds are quite common, and when a patent is issued, its claims are supposed to be free from these defects.

• Terms

The preference of general terms over specific terms in the phraseology of a claim is an expedient to which the inventor resorts in order to make the claim, and, therefore, his protection, as broad as possible. A claim in which the constituent elements of the invention and their functional relations to each other are defined in broad terms leaves room, without further inquiry, for a broad interpretation of the invention, while a claim in which the constituent elements and their functional relations are defined in specific terms tends to indicate that the invention is not susceptible of a broad interpretation.

However, breadth of language, while desirable, is more or less a matter of form; and when we analyze a claim, we must be guided by its spirit rather than by its letter. Equivalents—that is, true equivalents within the scope of the invention—are always included within the scope of a claim, and the doctrine of equivalents can be invoked where the terms of a claim are specific, but the invention which it defines is generic.

• Number of elements

A matter far more important to the inventor than the language of the claim is the question of whether it includes the least number of elements which are necessary to define the invention. The inclusion of any additional element in excess of the least number required introduces a limitation, and if an allegedly infringing device does not include all the elements which are recited in the claim, infringement will seldom, if ever, be found to exist.

As a rule, the inventor who has secured a broad claim, or possibly a few broad claims, also has narrower claims incorporated in his patent, and in the narrower claims he usually takes a firmer grip upon the embodiment of the invention which he has described. It is not necessary that the narrower claims include a larger number of elements than the broad claim since many limitations can be effected by qualifying the elements of the broad claim. A change of a single word in the broader claim or the addition of only one word to it is sometimes sufficient to make it narrower; and, where such fine distinctions are made, we have to look closely to determine which is the broadest claim.

The introduction of additional elements into the broad claim is another method of limiting it and adding to the number of claims, the only requirement being that the additional element and those of the broad claim must combine to produce a unitary result and not merely an aggregation. Narrow claims, in addition to broad claims, are generally desirable because the patent will then not stand and fall with the broad claims alone. Upon suit for infringement, the broad claim or claims may be held invalid, while the narrow ones may be held valid and infringed. Or, if the suit does not involve the narrow claims, an adverse judgment upon the broad claims may leave the narrow claims undisturbed, in which case the inventor could still assert rights of exclusion under the narrow claims, and these would be entitled to a presumption of validity like any other unadjudicated claim.

We see, therefore, that the claims are the most important part of any patent. If we want to know what the patent covers, we have to know what is in the claims. It is the claims, and the claims alone, on which the inventor is permitted to rely in asserting his right of exclusion—an elementary rule which cannot be emphasized too strongly.

RURAL LINE TRANSFORMER PROTECTION*

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Fig. 1

Like all other transformers, the rural line transformer (Fig. 1), or distribution transformer for rural service, needs to be protected from the dangers incident to its being subjected to voltages greater than its rated voltage. The overvoltages that a rural line transformer has to contend with are generally those induced by lightning disturbances, which practically always produce voltage or current waves having steep wave fronts. Because the locations for transformers of this type are remote in respect to proximity to substations (see Fig. 2) where large investments in electrical equipment and facilities are centered, the problem of adequately protecting these comparatively inexpensive, although very necessary, pieces of electrical apparatus is of major importance to any electrical system on which they are used.

The investigation for suitable protection leads to the best possible determination of two factors:

1—The impulse characteristics of the transformer and its associated equipment.

2—The means for limiting the surges or impulses to the transformer.

• Testing for impulse characteristics

With the facilities set up by the impulse laboratories of electrical manufacturers, accurate determination of the impulse characteristics of the transformer and its associated equipment becomes possible. In accordance with the standard procedure for this type of testing, an impulse test is conducted on a simple air gap, using a positive wave which rises to crest, the maximum voltage, in 1.5 microseconds and then decreases to 50 percent of crest value in 40 microseconds from the start of the wave. To obtain this wave, the constants, capacity, inductance, and resistance of the surge, or impulse generator are adjusted with the transformer connected in the circuit. After these adjustments have been made, the crest value of the wave is increased by increasing the charging voltage of the generator condensers. The wave impressed upon the unit will then always reach its crest value in the same time for voltages of any magnitude. Although the wave remains a 1.5 x 40 microsecond wave, its rate of voltage rise increases as the magnitude of the crest value is increased.

If this voltage is gradually raised with repeated application of the same voltage until flashover occurs about 50 percent of the time, the breakdown will occur several microseconds after the wave has reached the crest value. In other words, the breakdown will occur on the tail of the wave and at a voltage lower than the crest value. The crest voltage for this case is the minimum 1.5 x 40 voltage required to cause flashover or breakdown of the equipment being tested.

If the voltage is then raised only a small amount, breakdown will still occur on the tail of the wave, but the time to breakdown will be shortened. Increasing the voltage still more will result in breakdown on the front of the wave, or in less than 1.5 microseconds.

The volt-time characteristic curve of the test piece is then obtained by plotting the total time to breakdown against the crest value of voltage, as in Fig. 3. (It will be noted that the voltage at the time of breakdown is not used.)

* Presented at the October 24, 1938, meeting of the Wisconsin Utilities Association.

The impulse curve (A) reaches its crest value in 1.5 microseconds and then decreases at a rate that would bring it to 50 percent of crest value in 40 microseconds, but the test piece flashes over at 5.75 microseconds, point "a" in the illustration. This crest value is the lowest, or minimum 1.5 x 40 wave that would cause flashover. If the crest voltage is increased as in curve (B), flashover will occur in 2.15 microseconds. In the case of curve (C) flashover occurs at the crest, or in 1.5 microseconds. The volt-time curve can then be obtained by plotting the crest voltage of each wave against the time to breakdown for that wave. The volt-time curve for the test is thereby established.

Under service conditions, however, wave (A) may continue to rise at the same rate, instead of reaching its crest value in 1.5 microseconds. Projecting the front slope of (A) until it intersects the time-lag curve will show the voltage and time required to cause breakdown. In this case, the breakdown on curve (C) would occur in 1.9 microseconds, instead of the 5.75 microseconds with a wave reaching crest in 1.5 microseconds. As the rate of voltage rise increases, the time to breakdown decreases and the flashover voltage increases. For a rate of voltage rise corresponding to wave (A), the breakdown voltage is about 180 per cent of the minimum 1.5 x 40 value.

This illustrates the condition encountered in service — the voltage continues to rise until flashover occurs at some point.

Fig. 2

• Lightning arresters

Fig. 4 shows the comparative time-lag characteristics of a 9-12 kv valve-type arrester, a double gap made up of a 1.5 in. gap and a 1 in. gap in series, 15 kv insulation, a standard 4.5 in. rod gap, and a 15 kv bushing such as would be used on a 7200 volt rural line transformer. The 15 kv insulation curve is placed so that there must be added to it the same factor of safety as is included in the standard 60 cycle insulation test. In other words, such insulation would be tested at 34 kv for one minute, and since failure does not occur, likewise it would not occur for impulse voltages below this curve. Test waves (A) and (B) are the impulse tests required by the A. I. E. E. standards.

This comparison shows that, regardless of the rate of rise in voltage, the lightning arrester will always limit the voltage to values safely under the insulation curve. The double gap set for 1.5 in. plus 1 in. will protect the transformer from any voltage rising at a rate less than approximately 300 kv per microseconds. The bushing, if it is to meet customary 60 cycle values, and the 4.5 in. gap cannot be depended upon to offer satisfactory protection.

From this it will be seen that, if gaps are to be used to limit voltages to the transformers resulting from steep wave front surges, they must be set at reduced spacings. There is a limit, of course, as to how far the setting can be reduced without abnormally increasing the flashovers for waves having slow fronts.

The arrester curve of Fig. 4 is based only on one lightning arrester manufacturer's data, and is only the impulse breakdown. As soon as current flows through the arrester, an impedance voltage is set up. This voltage depends not only upon the magnitude of the current but also upon the rate of change of current. This particular arrester when discharging 10,000 amperes crest at 10,000 amperes per microseconds will have an impedance drop of approximately 80 kv.

• The use of gaps

If the protective device is a gap, the breakdown of the gap results in a short circuit on the system. In addition, most gaps continue to arc over until the voltage is removed, resulting in service interruptions. There may, however, be some rural lines

where the short circuit current is not sufficient to maintain an arc across the gaps. There are on the market several enclosed gaps which extinguish the arc when the fault current passes through zero.

Arresters are constructed of a number of small gaps in series with a resistance. The resistance characteristics are such that in the presence of a high voltage the resistance becomes quite low, thus enabling large discharge currents to be passed. When the presence of high voltage is removed, the resistance instantly increases to a value that will not permit an arc to be maintained across the series gaps of the arrester. The arrester is, therefore, automatically disconnected from the circuit and should not cause service interruptions.

• The transformer circuit

The transformer itself can be further considered by referring to the equivalent circuit of an interconnected transformer as shown in Fig. 5. C_1 represents the electrostatic capacity between the high voltage and low voltage windings. This capacity is too small to limit the voltage increase that may appear between windings. C_2 and C_3 are the capacities of the high voltage winding to the transformer tank and of the low voltage winding to the tank respectively on a small distribution transformer. As C_3 is approximately nine times C_2, if the tank is perfectly insulated, 90 per cent of the voltage between the high voltage and low voltage windings will appear between the high voltage winding and the tank and across the high voltage bushings. For a given value of surge current — both magnitude and rate of rise — the drop across the lightning arrester, across the arrester lead to ground, and across the ground resistance can be calculated. If solid interconnection is used and the connection between the arrester and the low voltage winding is short, the voltage between windings is practically the arrester impedance drop.

The potential of the tank is fixed by the capacitances C_2 and C_3. Since both of these capacitances are quite small, any leakage path from the tank to ground tends to reduce the tank potential to zero. When the tank potential is reduced to zero in this manner, the voltage across the high voltage bushings to the tank becomes the drop through the arrester, the ground lead, and ground resistance. The effectiveness of the arrester interconnection would, therefore, be neutralized, because it would permit the high voltage bushings to flash over and thus establish a 60 cycle fault path to ground, which would result in a service interruption. This undesirable effect can be overcome either by solidly connecting the tank to the low voltage neutral at the transformer or by inserting a small gap between the low voltage neutral bushing and the tank.

The sketch of Fig. 6 shows the position of the windings and tank for an interconnected installation. The voltage between windings is the arrester

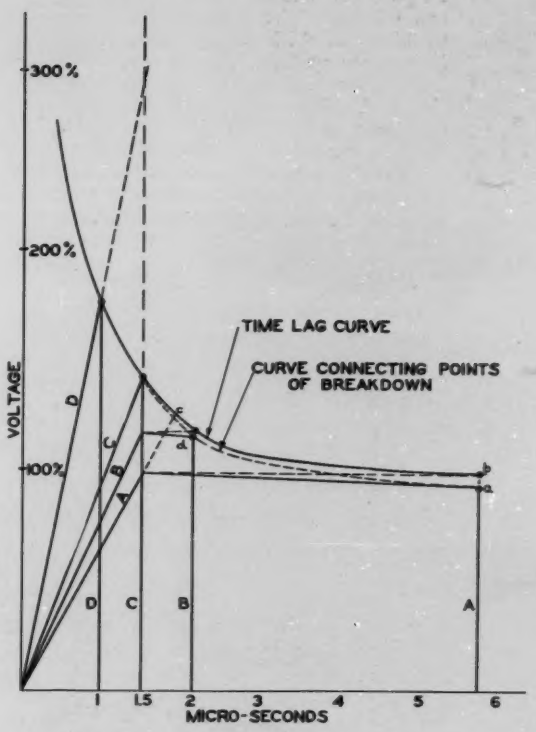


Fig. 3

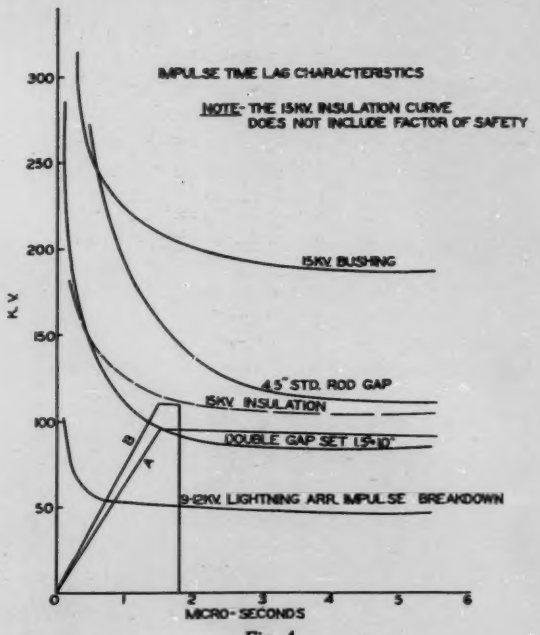


Fig. 4

impedance drop. If the tank is perfectly insulated, its potential will be just above that of the low voltage winding. The voltage across the high voltage bushings would be about 90 percent of the arrester impedance voltage. If a leakage path exists from tank to ground, the tank approaches ground potential, and voltage across the high voltage bushings increases to the total impedance drop to ground. With a gapped secondary, the tank moves away until the gap breaks down, which returns the tank to the potential of the low voltage coils and thus prevents flashover of the high voltage bushings.

• Comparative advantages

To properly protect a transformer against transient voltages, the limiting voltage device must keep all voltages, whatever their causes, lower than the breakdown voltage of the transformer insulation. The connections between the limiting device and the transformer must be kept as short as possible to avoid impedance drops, which at lightning frequencies and high currents become of considerable magnitude. To obtain the full benefit of the limiting device, its ground lead should be interconnected with the low voltage neutral and the transformer tank.

The only device meeting all of these requirements is the lightning arrester. Gaps afford protection only on the slower wave fronts. If the gaps are reduced to afford protection on the steeper wave fronts, the breakdowns for the slower waves approach 60 cycle over-potentials, with the possibility of frequent interruptions to service. Furthermore, the lightning arrester draws practically no 60 cycle current, while the gaps permit system short circuit current to flow for appreciable intervals of time depending upon the type of gap used.

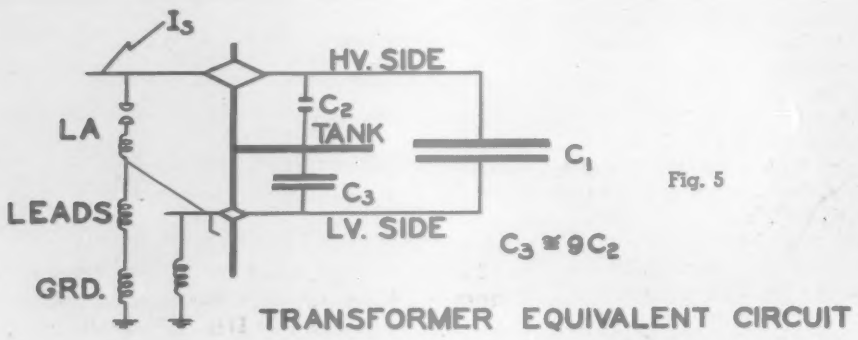


Fig. 5

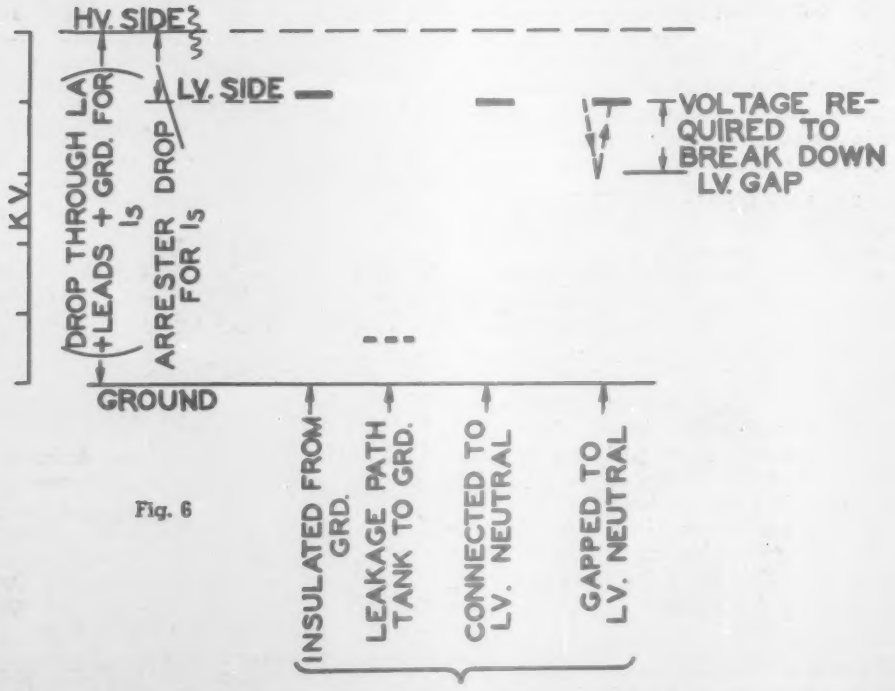
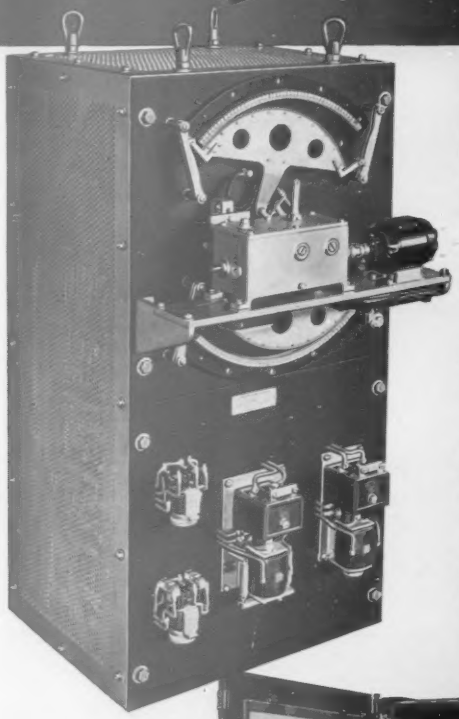


Fig. 6

ACCURACY! DEPENDABILITY! SPEED!



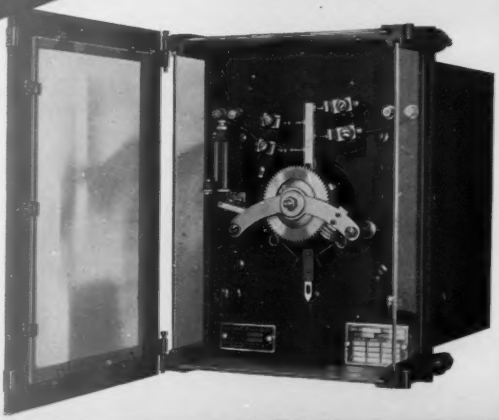
That's What You Get When You Install Allis-Chalmers Rocking Contact Generator Voltage Regulators! Learn How You Cut Maintenance Costs ... Get Better Service ... with the Equipment that Pays for Itself!

When fluctuating generator voltage runs up service costs ... when that fluctuation means loss in profits ... decrease in customer satisfaction ... that's a tough spot for every utility executive and engineer!

But you don't have to put up with that loss! Allis-Chalmers Rocking Contact Regulators control generator voltage ACCURATELY ... DEPENDABLY ... FAST!

Rocking Contacts move into action quickly! When the voltage changes, high speed contactors act within a few cycles, setting the excitation at exactly the value you want ... there's no variation once the change is made!

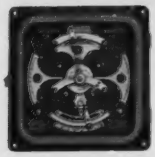
It doesn't matter what kind of generator you have ... Allis-Chalmers has a regulator designed to meet your needs! Get in touch with your nearest Allis-Chalmers District Office and learn how you can cut maintenance costs ... give better service ... with Rocking Contact Regulators!



ABOVE: Rocking Contact, Motor Operated Exciter Rheostat with High Speed Field Forcing Contactors.

• •

RIGHT: Voltage Sensitive Torque Motor Control Element for Panel or Bracket Mounting with Front Cover Open.



PAID FOR ITSELF IN 6 MONTHS!

One of the world's largest limestone processors found that with their former regulators the yearly cost of $200 for repairs was insignificant compared to the operating losses and cost of clearing crushing rolls. These rolls would stop when the voltage dropped, and invariably the crusher would be loaded when this occurred.

Then they installed Rocking Contact Regulators! Former delays through motor kickouts caused by low voltage on the interlock system have been eliminated. Operating costs have been cut 20%! The Regulator actually paid for itself in six months!

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EXTRA!

GET ALL THESE "EXTRAS" IN ALLIS-CHALMERS OIL CIRCUIT BREAKERS WITH "QUICK-QUENCH" RUPTORS!

1. **EXTRA LOW MAINTENANCE COST!** Oil carbonization and contact deterioration are cut to a minimum by "QUICK-QUENCH" action!

2. **EXTRA HIGH INTERRUPTING CAPACITIES!** Massive arcing contacts, large margins of safety, easy arc extinction with "QUICK-QUENCH" Ruptors.

3. **EXTRA FAST RECLOSING TIME!** Available with Allis-Chalmers Ruptor-equipped Oil Circuit Breakers are high speed reclosing operators, which restore service well within the new NEMA standard.

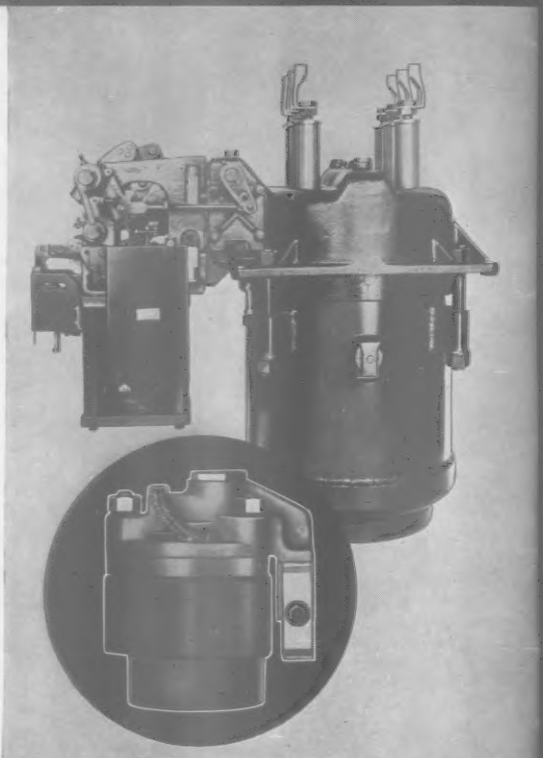
4. **EXTRA QUICK SERVICING!** Ruptors are easy to get at for inspection and servicing. They don't waste the time of your maintenance men!

5. **EXTRA "BREAKS" FOR YOUR MONEY!** You get consistent operation without constant attention. Ruptors' "QUICK-QUENCH" action enables an oil circuit breaker to handle many more circuit interruptions before requiring inspection and renewal of oil and contacts.

6. **EXTRA RESEARCH AND TECHNICAL FACILITIES!** Technical engineering research is continually in progress in Allis-Chalmers laboratories, in those of associated companies throughout the world, and in thousands of installations in the field. You get the benefits!

Get the details. Get all the facts. Let the Allis-Chalmers representative in the District Office nearest you give you the whole story on "QUICK-QUENCH" action . . . on what Allis-Chalmers "extras" can do for you!

MR. PHIL. PAUL,
SAN ANTONIO OFFICE
34



CHOSEN FROM TWENTY-THREE separate and distinct designs for an interrupting device was the "Ruptor," shown here. After exhaustive tests, it was developed to its present high efficiency and incorporated in oil circuit breakers, such as the one shown here.

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